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Fluid Contamination Project

Report No. 6

Prepared for:

Oklahoma City Air Materiel Area

Tinker Air Force Base, Oklahoma

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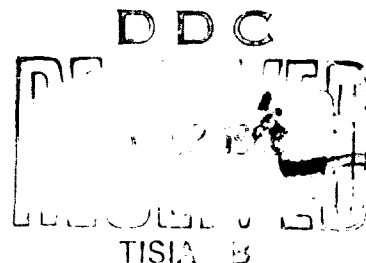
Fluid Power Controls Laboratory

School of Mechanical Engineering

OKLAHOMA STATE UNIVERSITY

Stillwater, Oklahoma

FLUID CONTAMINATION PROJECT

Report No. 6

STUDY IN THE FIELD OF FLUID CONTAMINATION

Contract With

OKLAHOMA CITY AIR MATERIEL AREA

Tinker Air Force Base, Oklahoma

Contract No. AF 34(601)-14090
Order Number 63-3

August, 1963

E. C. Fitch, Project Leader

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FOREWORD

This report was prepared by the School of Mechanical Engineering, Oklahoma State University, Stillwater, Oklahoma, under USAF Contract AF 34 (601)-14090.

The present report summarizes the progress made on methods of cleaning, design of associated equipment, and the evaluation of hydraulic component cleanness. The knowledge and experiences gained since February 1959, the first OCAMA-sponsored Fluid Contamination, together with the test facilities obtained have been instrumental in the accomplishments of this study. Previous studies have had as their objectives the following:

1. Survey of pertinent material on Fluid Contamination available in the literature.

2. An experimental evaluation of sintered type filter media.

3. A state-of-the-art survey of cyclone separation with experimental studies.

4. An analytical and experimental study of available cyclone separator theories.

5. An engineering study of conventional filter element cleaning and evaluation.

6. Cleaning methods required to restore filter elements to serviceable condition and methods for establishing the degree of element interstitial cleanliness.

7. A study of particle counting and sizing.

8. A study of the use of ultrasonic power in filter cleaning.

The results of the studies cited above have been reported in OSU's annual reports to OCAMA (Reports 1 through 5).

The studies represented by this report include the following:

1. Investigation of methods of utilizing mutually selected solvents (Freon T. F., trichloroethylene) in conjunction with ultrasonic cleaning equipment.

2. Comparison tests between removing solids from cleaning solvents by distillation and mechanical filtration.

3. A study of the determination of hydraulic component cleanliness using a HIAC automatic particle counter in conjunction with ultrasonic cleaning equipment.

4. Detailed engineering drawings of an ultrasonic cleaning facility.

5. Design and fabrication of a cleaning fluid stand and temperature controller stand.

PROJECT PERSONNEL

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M. E. Reynolds   Report Editor

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INTRODUCTION

The OSU Filter Evaluation Laboratory has for some time now been working with OCAMA in an effort to bring the state-of-the-art of hydraulic component cleaning and cleanliness evaluation to a more exact science. In an effort to make this cleaning and evaluation a more exact science, OCAMA proposed the following work statement which constitutes the objectives of Air Force contract, AF 34(601)-14090:

1. Complete engineering drawings for an operational cleaning facility based upon the experienced gained at OCAMA and OSU in filter cleaning;

2. Study of the methods of utilizing mutually selected solvents in conjunction with ultrasonic cleaning equipment;

3. Comparison tests for the removal of solids from cleaning solvents by distillation and mechanical filtration;

4. A study of hydraulic component cleanliness using a HIAC automatic particle counter in conjunction with ultrasonic equipment;

5. Design and fabrication of a clean fluid stand and temperature controller stand.

The objectives of the aforementioned work statements have been completed and presented as Interim Reports one (1) through six (6). This report consists of these six Interim Reports and is a summary of the work performed during this contract period.

Many of the ideas concerning the necessary design requirements of

cleaning equipment have changed during the second half of the contract

period.   These changes when applicable have been made and are included in

this report.

CONCLUSIONS AND RECOMMENDATIONS

I. Introduction

Considerable progress has been made by OSU and OCAMA in the area of cleaning and cleanliness evaluation of prime hydraulic components. With the knowledge gained during this contract period, production cleaning and evaluation of prime hydraulic components cleanliness can be accomplished. The work statement as outlined in Air Force contract 34 (601)-14090 had as its objectives (1) the design of an ultrasonic cleaning unit; (2) a study and evaluation of reliable cleaning solvents; (3) a study of the cleanability of these solvents by distillation and/or mechanical filtration; (4) determination of hydraulic component cleanliness using the HIAC particle counter and (5) assisting OCAMA in establishing necessary cleaning and evaluation procedures and specifications. As a result of the work necessary to accomplish these objectives, hydraulic component cleaning and cleanliness evaluation can be determined.

However, since the procedures formalized at OSU have not been used in field cleaning and evaluation, it seems appropriate and is recommended that OCAMA apply these procedures on carefully monitored production activities for at least one year. Although every effort was made to make the procedures applicable to field operation, certain difficulties are sure to be encountered in the transition of the procedures established at OSU and the working procedures required at OCAMA.

II. Orthodichlorobenzene - Filter Compatability

One of the major problems encountered in the cleaning of various hydraulic components is the use of chemicals that are incompatible with the materials from which the components are made. Some concern had been expressed on the detrimental effect of orthodichlorobenzene (Carbon Remover,MIL-C-25107) to the epoxy resins of the F-105 aircraft filter elements. In order to determine the effects of Carbon Remover, MIL-C-25107, on the epoxy resins of these aircraft filters, the Filter Evaluation Laboratory of Oklahoma State University performed specified tests on four F-105 aircraft filter elements. These four filter elements were slected at random from the supply of F-105 filter elements obtained for the F-105 study as presented in Interim Report 62-2. The filter elements were subjected to ultrasonic energy while immersed in Carbon Remover, MIL-C-25107.

The results of these tests indicated that the filter elements apparently were not harmed as a result of the cleaning cycle performed. This conclusion was based upon the bubble-point pressure recorded and upon visual inspection of each element before and after cleaning.

III. The General Cleaning Facility

A major portion of the work performed during the first half of the present contract period was the design and preparation of complete engineering drawings for an operational ultrasonic cleaner. The design of the ultrasonic cleaner had been generally established by previous test programs and the cleaning cycle was patterned to implement the process presented in OCAMA exhibit NER 62-6-1.

The specifications for the proposed facility consisted of verbal objectives which were mutually developed into detailed instructions.

All major decisions involving facility design and component selection were coordinated with the OCAMA project monitor.

The design of the ultrasonic cleaning facility was aimed at reducing the handling of the chemicals and resultant spillage, and at providing a ventilation system for the chemicals.

However, the results obtained during the last half of the contract period indicate that distillation of the cleaning fluid appears to be the more logical approach of obtaining clean fluid for the cleaning and evaluation of aircraft hydraulic components. Therefore, it seems appropriate that a closer look into the recovery of the contaminated solvents should be made in the initial cleaning stages when large amounts of contaminant are being removed.

IV. The Cleaning Fluid Stand

The basis upon which hydraulic component cleanliness evaluation is to be made necessitates the availability of large amounts of clean fluid. The contaminant level of the clean fluid must be consistent for use in the evaluation of hydraulic component cleanliness. With these necessary conditions in mind, OSU personnel designed and built a clean fluid stand.

The stand as presented in Interim Report 63-5 consists of a pump, a filter (Hilco, 0.5 micron, nominal) and a provision for filtering fluid through any combination of three in-line Millipore filters downstream from the Hilco filter. With this clean fluid stand, various degrees may be obtained for cleaning or component cleanliness evaluation.

Results of the tests performed on trichloroethylene and Freon T. F. show that fluid obtained from this stand, which is not located in the clean room at OSU, can be filtered to a finer degree than that obtained

by triple filtering the fluid in the clean room at OSU.

The degree of cleanliness of the fluid is based upon the results obtained from the HIAC automatic particle counter. The possibility then arises that the fluid obtained at the stand is cleaner than that presented to the counter because of sample preparation and counting. Experience as well as tests performed at OSU have shown that anytime a fluid sample is transferred from one container to another, a difference in particle count is inevitable. This situation occurs when obtaining a sample to be analyzed by the HIAC automatic particle counter.

Enough emphasis cannot be placed upon the usefulness of the HIAC particle counter to formalize necessary handling and cleaning procedures. The procedures presented in this report were formalized using the HIAC automatic particle counter.

V. Hydraulic Component Cleanliness Evaluation

Evaluation of hydraulic component cleanliness was based upon the particle count of particulate contaminant removed from the components. The cleanliness evaluation of the components was made using aircraft hydraulic filter elements because of their availability and complexity with regard to cleaning. These filter elements, part of the elements reported on in Interim Report 62-3, were subjected to various cleaning cycles, and the contaminant removed during each cycle was monitored by the use of a HIAC automatic particle counter. A plot was then made of particle count versus cumulative cleaning time. This work was performed using both Freon T. F. and trichloroethylene.

The results of the tests on cleaning of these filter elements revealed the following facts:

1. From a particle contaminant removal basis, trichloroethylene appears to be the better solvent;

2. The number of cleanings necessary to reach a steady state cleanliness level is dependent upon the cleaning power of the particular solvent;

3. Trichloroethylene was able to remove some particulate matter that Freon T. F. could not.

Based upon these results, trichloroethylene appears to be the better solvent for cleaning filter elements because of its ability to reach the steady state value of contaminant removal in a shorter length of cleaning time.

The comparison tests for the above solvents consisted of monitoring the particle removal rate of contaminant from filter elements that had been cleaned using trichloroethylene and Freon T. F. The elements that

had been cleaned in trichloroethylene were then cleaned in Freon T. F. and those cleaned in Freon T. F. were then subjected to one cleaning cycle in trichloroethylene. The results of these tests conclusively showed that trichloroethylene was able to remove more contaminant from the filter elements than Freon T. F.

However, the results of the dirt capacity tests run on each element indicated that there was no significant difference in the amount of AC Fine Test Dust that the elements were able to hold. This was not considered too significant because a high degree of cleanliness was achieved in both types of tests and dirt capacity values are not precise enough to distinguish such conditions. In each case, the element cleaned with both solvents showed comparable results and were presented in Interim Report 62-3.

VI. Recommendations

Considerable progress has been made during the present contract period in the area of cleaning and evaluation of prime hydraulic component cleanliness. With the knowledge gained during this contract period production cleaning and evaluation of prime hydraulic component cleanliness can be implemented and fully applied.

In order to implement this program, necessary ultrasonic equipment for this work has been designed, necessary testing and evaluation procedure have been established, and studies have been made on the cleaning and reclaiming of contaminated solvents to be used in the cleaning program.

As a result of the work performed during this contract period, hydraulic component cleaning and cleanliness evaluation can now be performed as a more exact science.

The objectives of the work statement of Air Force contract 34(601)-14090 have been completed and are now ready to be adapted to field level and production type cleaning and evaluation. As a result of these studies, the following recommendations are made:

1. A redesign of the OSU ultrasonic cleaner to include a means of obtaining distilled fluid as the primary method of recovering the contaminated cleaning solvents in the initial cleaning stages, based upon the results of the work during the second-half of the contract period;

2. The design and fabrication of a clean fluid stand patterned after the OSU design to enable OCAMA personnel to obtain large quantities of clean fluid for cleaning and evaluation works;

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3. The purchase of a HIAC Automatic Particle Counter to be used by OCAMA in their training program and as a means of formalizing new testing and evaluation procedures;

4. The acquisition of an automatic distillation unit to be used in conjunction with present ultrasonic cleaning units in order to have available large amounts of clean solvents.

As it is in many instances of research in new areas, each idea or concept propagates a host of others. Each new idea or concept requires analysis and redirection of efforts toward the objectives of the project work. The state-of-the-art to date shows that it is now possible to define and assign a quantitative value to component cleanliness. However, these values merely show how clean a component can be made, but they show nothing about how clean a component should be in order to perform properly for a predetermined life. This predetermined life, based upon a contaminant tolerance level, must then be the new area of study. That is, the amount and size-distribution of contamination that a system can acquire, and to continue to function properly for a predetermined life, must be defined. Only after these factors have been defined can the problems associated with the ever present contaminants be solved.

It is hoped that OCAMA will support work in this new area in the future so that the design of new and the maintenance of existing equipment can be made compatible with the contaminant levels that must prevail in operational systems.

INTERIM REPORT NUMBER 63-1
ORTHODICHLOROBENZENE-FILTER COMPATABILITY

Ref: Contract AF 34(601)-14090
        Order Number 63-3

Date: 1 November 1962

School of Mechanical Engineering
Oklahoma State University
Stillwater, Oklahoma

PROJECT PERSONNEL INVOLVED IN STUDY

E. C. Fitch   Project Leader

J. E. Bose   Assistant Project Leader

R. H. Tucker   Research Associate

M. E. Reynolds   Report Editor

INTRODUCTION

One of the problems encountered in the cleaning of filters is the use of chemicals that are incompatible with the materials from which the filters are made. There has been some concern that the Carbon Remover (orthodichlorobenzene), Mil-C-25107, used in the ultrasonic cleaner in a previous test may have been harmful to the epoxy resins of the F-105 aircraft filters. To determine the effects of Carbon Remover, Mil-C-25107, on the epoxy resins of these aircraft filters, Mr. Thomas H. Edgin of OCAMA requested that the Filter Evaluation Laboratory of Oklahoma State University perform specified tests on four F-105 aircraft-filter elements.

TEST PROCEDURES

Four E-8, F-105 filter elements were selected at random from the supply of F-105 filters previously received for contract AF 34(601)-9879. Information from Interim Report No. 62-2 on the F-105 Filter Evaluation showed that the four filters chosen for the orthodichlorobenzene test were service-contaminated elements with from 142 to 197 hours of service. After the filters were received by the Filter Evaluation Laboratory, they had been dirt-loaded to capacity with AC fine dust and left in this condition.

The bubble-point pressure is an indication of pore size; therefore, any notable decrease in the bubble point measured before and after cleaning would suggest damage to the filter elements and possibly would mean that the epoxy resins on the filters had been harmed during the cleaning cycle. Prior to cleaning the elements, the bubble-point pressure (in inches of water) was measured by immersing the elements in Solox in the OSU-constructed Bubble Test Stand.

To clean the filter elements, OSU engineers submerged the four elements together in a beaker of orthodichlorobenzene which was suspended in a Westinghouse Ultrasonic Cleaner. During the thirty-minute soaking period, the elements were subjected to continuous ultrasonic vibrations transduced through the Carbon Remover, Mil-C-25107. Since orthodichlorobenzene is volatile at elevated temperatures, the soaking bath was maintained at room temperature as a safety precaution.

After the cleaning process, the elements were flushed with hot water to remove the orthodichlorobenzene used in the ultrasonic cleaner. The water temperature was approximately 160°F.

Because the wet filter elements dry slowly at room temperature, due to the collection of water in the pores of the elements, it was felt that rapid drying of the elements was necessary to allow the bubble point test to be performed. Water on the elements was removed by immersing them in a beaker of alcohol while the beaker was subjected to the ultrasonic vibrations. The elements were left in the alcohol only long enough to insure their complete coverage by the alcohol. After removing the elements from the alcohol, they were dipped in petroleum ether to guarantee their rapid drying at room temperature.

When the elements were dry, they were again put in the Bubble Test Stand and their bubble pressure measured. The bubble pressures of each element, taken before and after cleaning, are included in Table V so that they can be easily compared.

The amount of contaminant a cleaned element will hold is an indication of how clean it is. To determine whether the elements were thoroughly cleaned during the cleaning process, OSU engineers performed tests to find the Actual Dirt Capacity (ADC) of the cleaned E-8, F-105 filter elements. The test was made in the following order:

1. The relief valve in the companion housings of the respective elements was blocked closed so that none of the circulating fluid would by-pass the elements during the test.

2. The companion housing, without the element, was installed in the system of the Artificial Contaminant Loading Stand which

was described in Interim Report No. 62-2, F-105 Filter Evalua-tion. The above cited system executed the pumping Mil-H-5606 hydraulic fluid through the installation at rated flow. For the E-8, F-105 aircraft filters, the rated flow is 8 gal/min. The contamination level of the circulation fluid is maintained at 2 microns absolute, prior to the dirt injection, by a control filter installed upstream from the test.

3. When 100°F steady-state conditions were reached in the circulat-ing hydraulic fluid, the tare pressure-drops (pressure drop measured across the test run where the filter housing is installed without the element in place) were recorded.

4. The element was then installed in the companion housing in the prescribed manner and the circulation resumed.

5. Again 100°F steady flow conditions of the hydraulic fluid were reached before artificial contaminant (a slurry of AC fine test dust in hydraulic fluid) was injected upstream from the test run in .1 gm. and .2 gm. contamination increments. The gross pressure-drop (pressure drop measured across the filter elements installed in the housing) was measured one minute after each addition of contaminant. Contaminant was added to the hydraulic fluid until a sharp increase in the pressure drop was observed above normal relief valve setting indicating the element was sufficiently dirt loaded.

6. To obtain a thorough mixing of the contaminant solution (AC fine test dust and hydraulic fluid), bottles of the mixture were placed in the Ultrasonic Cleaner. The ultrasonic energy diffuses

the agglomeration of particles in the mixture and thereby insures a complete disperson of the particles on the elements during the dirt loading process.

Results of the tests are shown in the graphs, Figures 3-1, 3-2, 3-3, and 3-4, and in the tabulations, Tables 3-1, 3-2, 3-3, and 3-4.

CONCLUSIONS

The epoxy resins on the filters apparently were not harmed as a result of the cleaning cycle performed. This conclusion is based upon the bubble-point pressure recorded and upon visual inspection of each element before and after cleaning.

A dirt loading test on each of the elements was made, as requested. Graphs and tables showing the data collected are included in this report.
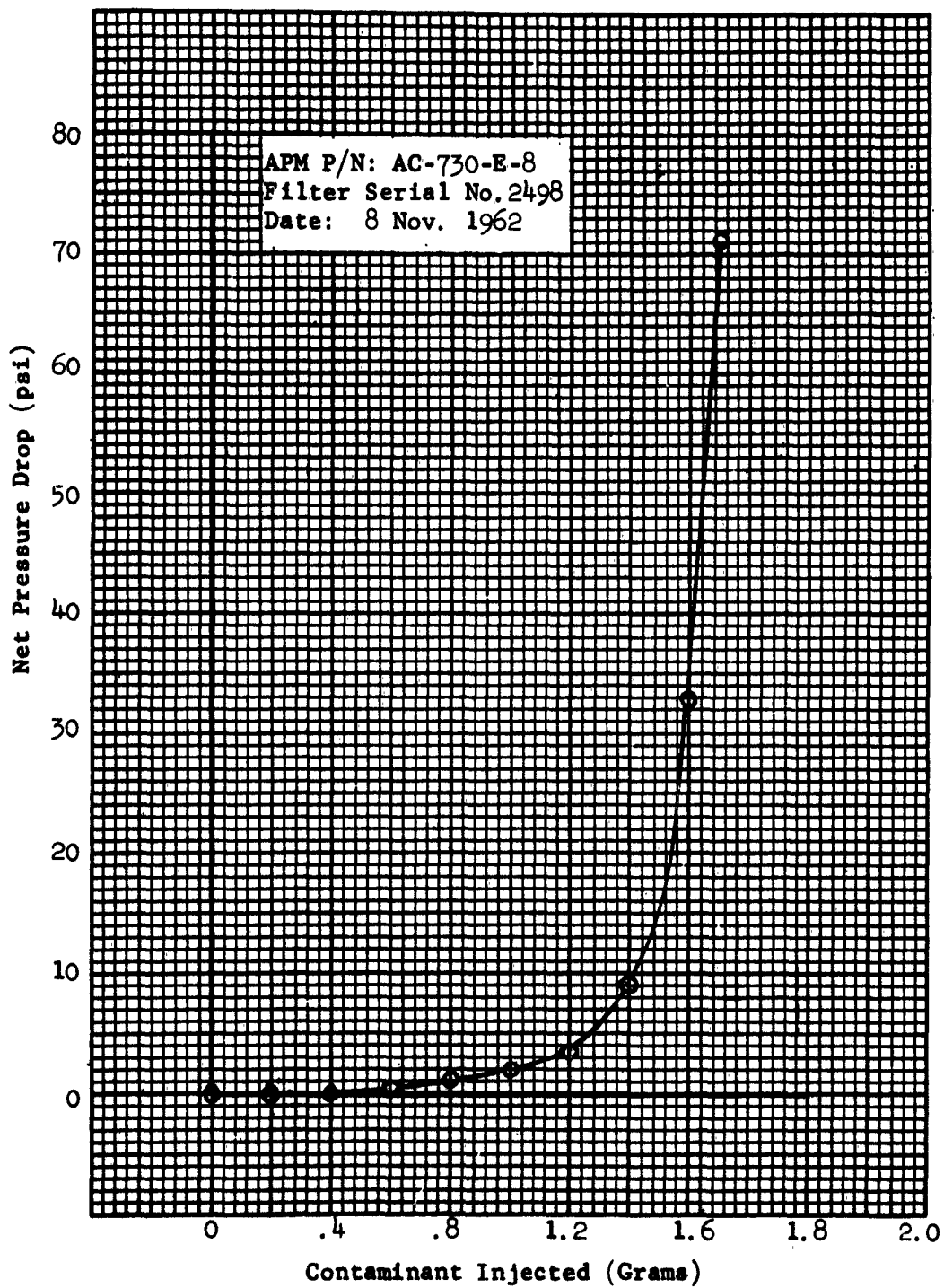
Figure 3-1. Contaminant Capacity Curve.

3-9
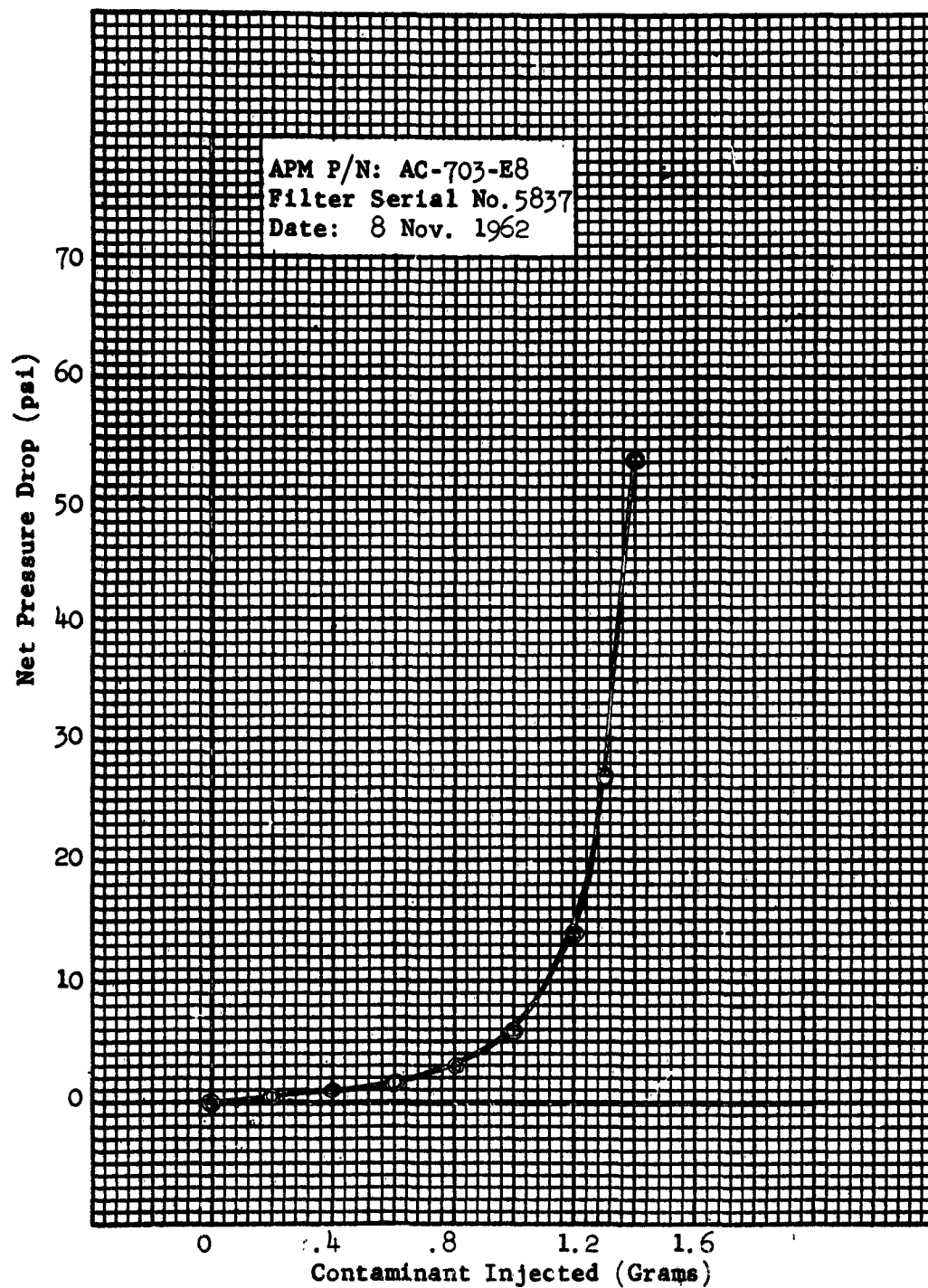
Figure 3-2. Contaminant Capacity Curve.
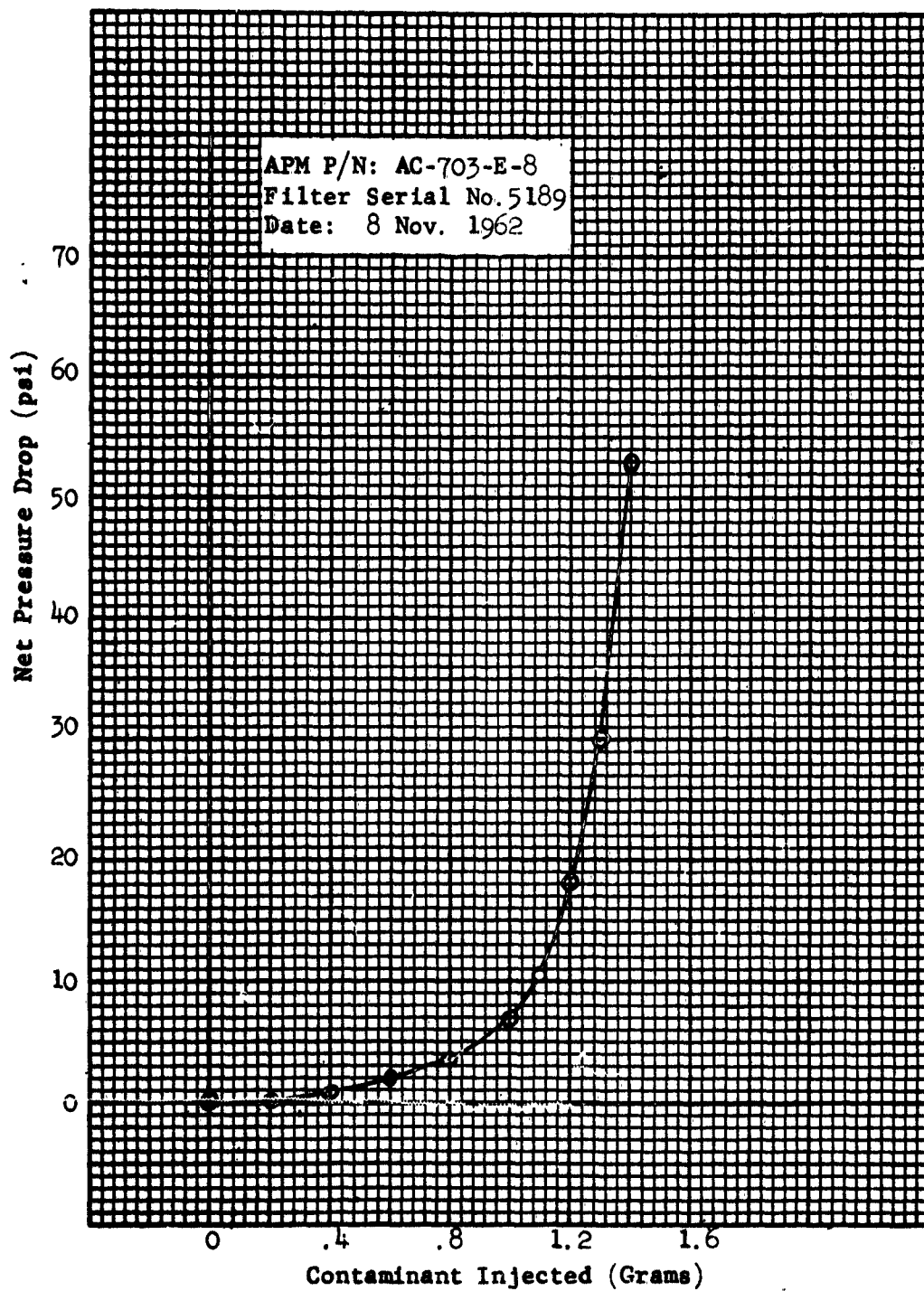
Figure 3-3. Contaminant Capacity Curve.
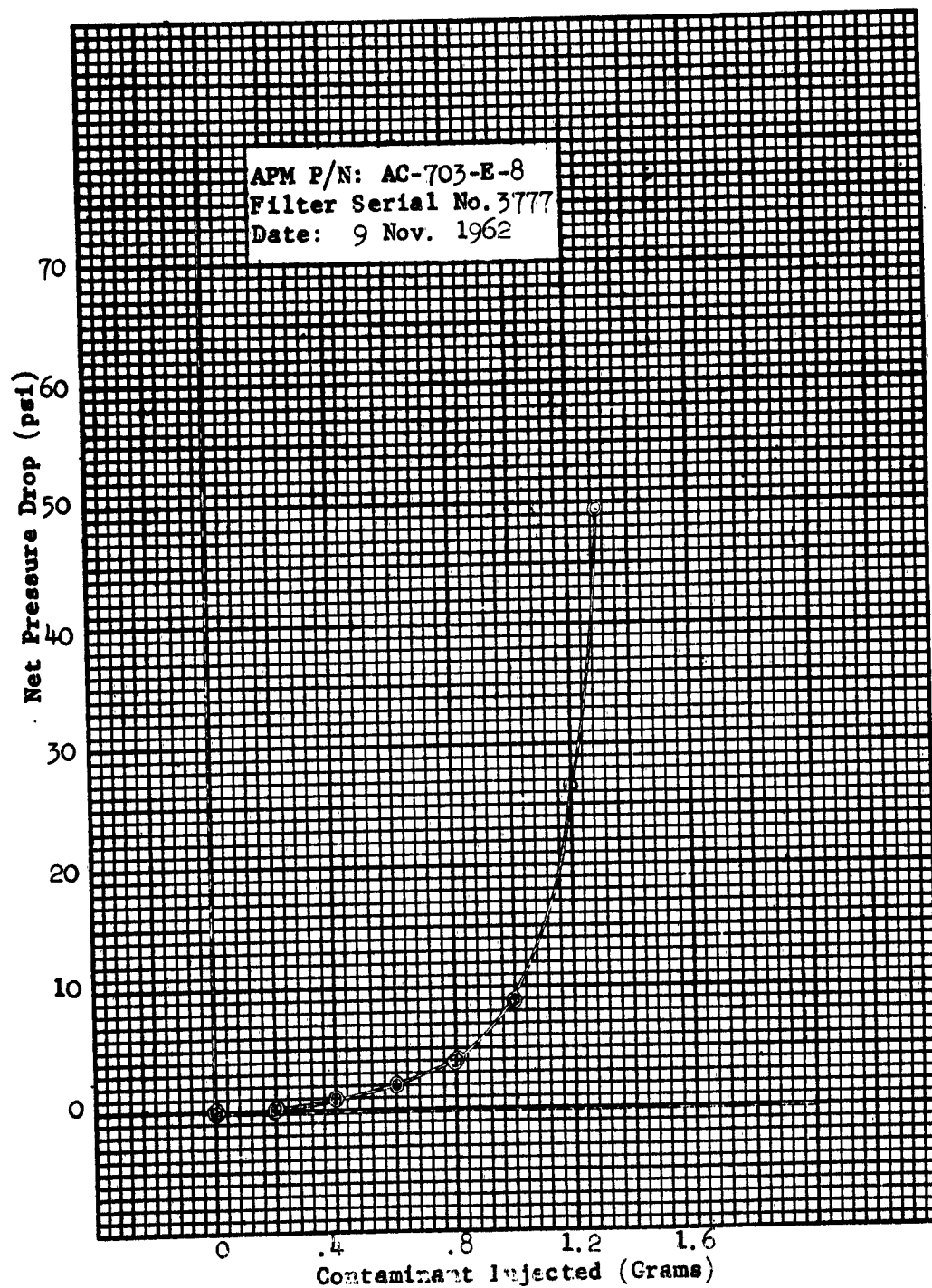
Figure 3-4. Contaminant Capacity Curve.

TABLE 3-1

FILTER DATA

FILTER P/N AC-730-E8 AIRCRAFT F-105 SERIAL NUMBER 2498
NOMINAL MICRON RATING 5 RATED FLOW 8 GPM RELIEF PRESSURE
BUBBLE POINT PRESSURE TEST TEMPERATURE 100°F HOUSING TARE 7.5

PRESSURE DROP TEST		CONTAMINANT CAPACITY TEST			
Q(GPM)	ΔP (PSI)	GRAMS	ΔP (PSI)	GRAMS	ΔP (PSI)
		0.0	8.50		
		0.2	8.50		
		0.4	8.65		
		0.6	8.90		
		0.8	9.40		
		1.0	10.20		
		1.2	12.05		
		1.4	17.50		
		1.6	41.20		
		1.7	79.80		

CONTAMINANT A.C. Fine   DATE: 8 November 1962
REMARKS:

TABLE 3-2

FILTER DATA

FILTER P/N AC-703E-8 AIRCRAFT F-105 SERIAL NUMBER 5837

NOMINAL MICRON RATING 5 RATED FLOW 8 GPM RELIEF PRESSURE

BUBBLE POINT PRESSURE TEST TEMPERATURE 100°F HOUSING TARE 7.5

PRESSURE DROP TEST		CONTAMINANT CAPACITY TEST			
Q(GPM)	ΔP (PSI)	GRAMS	ΔP (PSI)	GRAMS	ΔP (PSI)
		0.0	8.60		
		0.2	9.00		
		0.4	9.35		
		0.6	10.10		
		0.8	11.30		
		1.0	14.45		
		1.2	22.30		
		1.3	35.60		
		1.4	61.80		

CONTAMINANT A.C. Fine   DATE: 8 November 1962

REMARKS:

TABLE 3-3

FILTER DATA

FILTER P/N __AC-703E-8__ AIRCRAFT __F-105__ SERIAL NUMBER __5189__
NOMINAL MICRON RATING __5__ RATED FLOW __8GPM__ RELIEF PRESSURE _____
BUBBLE POINT PRESSURE _____ TEST TEMPERATURE __100°F__ HOUSING TARE __7.5__

PRESSURE DROP TEST		CONTAMINANT CAPACITY TEST			
Q (GPM)	ΔP (PSI)	GRAMS	ΔP (PSI)	GRAMS	ΔP (PSI)
		0.0	9.60		
		0.2	9.80		
		0.4	10.30		
		0.6	11.40		
		0.8	13.00		
		1.0	16.35		
		1.1	20.13		
		1.2	27.60		
		1.3	39.50		
		1.4	62.80		

CONTAMINANT __A.C. Fine__ DATE: 8 November 1962
REMARKS: _____

TABLE 3-4

FILTER DATA

FILTER P/N __AC-703E-8__ AIRCRAFT __F-105__ SERIAL NUMBER __3777__
NOMINAL MICRON RATING __5__ RATED FLOW __8 GPM__ RELIEF PRESSURE_____
BUBBLE POINT PRESSURE_____ TEST TEMPERATURE __100__°F HOUSING TARE __7.5__

PRESSURE DROP TEST		CONTAMINANT CAPACITY TEST			
Q(GPM)	ΔP (PSI)	GRAMS	ΔP (PSI)	GRAMS	ΔP (PSI)
		0.0	8.90		
		0.2	9.20		
		0.4	9.70		
		0.6	10.80		
		0.8	12.70		
		1.0	17.60		
		1.2	35.50		
		1.3	58.30		

CONTAMINANT __A.C. Fine__ DATE: 9 November 1962
REMARKS:_____

TABLE 3-5

ELEMENT NO.	INITIAL BUBBLE PT. (in. of water)	FINAL BUBBLE PT. (in. of water)
3777	16.9	16.60
2498	16.9	16.90
5189	16.9	16.80
5837	16.0	16.0

INTERIM REPORT NUMBER 63-2
THE GENERAL CLEANING FACILITY

Ref: Contract AF 34(601)-14090
      Order Number 63-3

Date: 24 January 1963

School of Mechanical Engineering
Oklahoma State University
Stillwater, Oklahoma

PROJECT PERSONNEL

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J. E. Bose	Assistant Project Leader
J. H. Cole	Graduate Assistant
H. Engja	Graduate Assistant
D. H. Neff	Draftsman
M. E. Reynolds	Report Editor

SUPPORTING PERSONNEL

R. E. Bose	Instructor
R. E. Reed	Instructor

INTRODUCTION

Considerable study has been made recently by OCAMA and the Filter Evaluation Laboratory of Oklahoma State University on improving methods of cleaning the filter elements of aircraft hydraulic systems. At the present time, the most effective method of cleaning the elements has been found to be a combination of chemical treatment and ultrasonic energy.

To determine the most satisfactory operating conditions for the removal of contamination by an ultrasonic cleaner, OSU and OCAMA have performed numerous tests with ultrasonic cleaners during the past year. Having selected the preferred cleaning cycle, OCAMA has requested that OSU engineers design and provide engineering drawings for an operational filter-element cleaning facility using mild chemical cleaning agents in conjunction with ultrasonic cleaners. The cleaning cycle requirements have been generally established by previous test programs, and an outline of these requirements is contained in OCAMA exhibit NER 62-6-1. Based on this exhibit, a cleaning cycle was developed for the proposed cleaning facility with the following procedure:

1. Soaking the filter elements in Carbon Remover, MIL-C-25107 (Orthodichlorobenzene), in the wash tank of an ultrasonic cleaner.

2. Rinsing with hot (180° To 200° F.) tap water to
flush away the Carbon Remover.

3. Drying the elements with a hot-air dryer.

4. Immersing the elements in another ultrasonic cleaner,
filled with filtered trichloroethylene, O-T-634a.

5. Immersing the filter elements in an ultrasonic cleaner
filled with trichloroethylene filtered to .5 micron
normal, to test the cleanness of the elements.

The specifications for the proposed facility consisted of verbal
objectives which were mutually developed into detailed instructions.
All major decisions involving facility design and component selection
were coordinated with the OCAMA project monitor. The result of this
joint effort has been the design of a desirable production-type facil-
ity suitable for implementing into the OCAMA or any depot level opera-
tion.

While the method of ultrasonic cleaning with chemicals has been
found to work well, problems connected with the use of orthodichloro-
benzene and trichloroethylene have become evident. Since direct
contact with these chemicals is to be avoided as much as possible,
and since it is conceivable that prolonged breathing of the chemicals
is injurious to the operating personnel, OSU has designed a cleaning
facility that attempts to minimize these hazards. The system set forth
in this report aims at reducing the handling of the chemicals and re-
sultant spillage, and at providing a ventilation system for the chem-
icals. Toward cutting down spillage, the OSU-recommended design
included wash tanks that are slightly recessed at the top, and, in the

chemical flow system, mandatory low-pumping speed on the barrel-to-tank-filling phase. The chemical flow system mechanically transfers the cleaning chemicals between the storage barrels and the ultrasonic cleaning tanks.

Although this cleaning facility is designed primarily for cleaning aircraft hydraulic filter elements, its use is not limited to these articles. The system is capable of cleaning anything that will fit into the units and that is compatible with the cleaning chemicals.
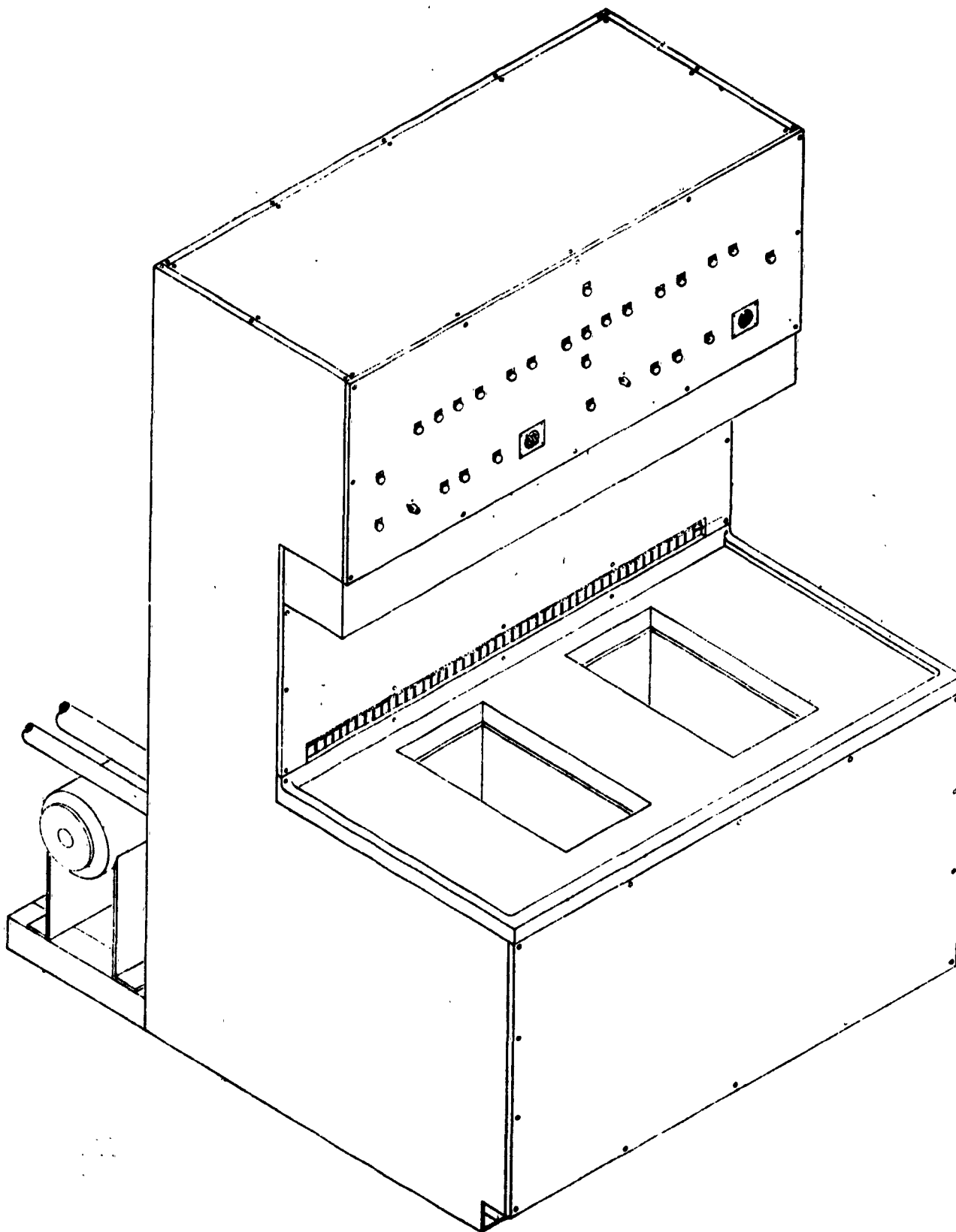
Fig. 4-1   Isometric View of Ultrasonic-Chemical Cleaner
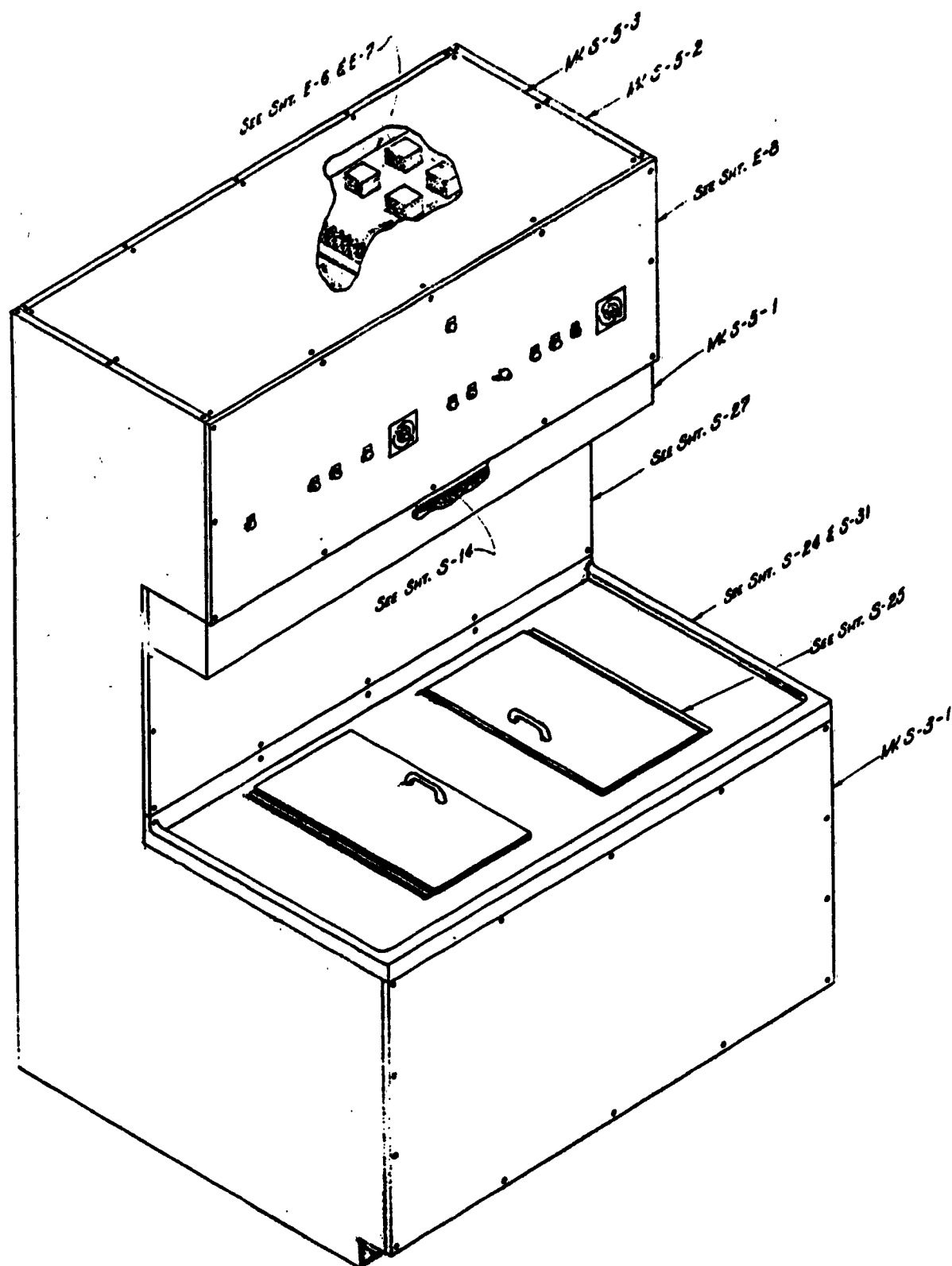
Fig. 4-2 Isometric View of Rinse-Drier Unit

THE CABINETS

The complete element-cleaning facility design for OCAMA consists
of four separate stainless-steel cabinets, all 6½ feet high. Three of
the cabinets, each containing two ultrasonic cleaning units, are iden-
tical, Fig. 4-1. The fourth cabinet contains the rinser and dryer,
Fig. 4-2.

Partly overhanging the work area of each cabinet is a vertical,
easily reached control panel, complete in each independently controlled
cabinet. For convenience, the work area on all the cabinets is a uni-
form 30 inches high. Each cabinet occupies a floor space of 55" width
and 59½ " depth.

All ultrasonic equipment is concealed inside the three ultrasonic
cabinets, the cleaner wash tanks being exposed only to the top side,
sink fashion. To reduce spillage and facilitate drainage, the edges
of the tanks are recessed 5/8 inch.

Excessive fumes from the chemicals are drawn off through a 2 inch
slot cut across the length of each ultrasonic cabinet immediately above
the tanks. Covered with a stainless-steel grille, the slot is con-
nected to the fan duct by a rectangular-to-round transition piece. A
fan is mounted behind each ultrasonic cabinet.

The stainless-steel paneling of the cabinets is fastened to an
angle-iron framework by recessed panel-screws that are covered with

plug buttons. The removable panels on the operating unit cabinets offer a built-in safety factor. Mounted on the panels enclosing the rear of each cabinet is a main-circuit disconnecting switch which must be turned to the "off" position before the back-side panel can be detached. Mechanical interlocks connect the side panels to the back panels, and the control-panel face to the side panels, insuring back-panel removal and "power off" before the high-voltage equipment is accessible.

The base of all cabinets is supported by channel iron. "Kick-space" is provided beneath the front of the cabinet, and receptacles are provided in the base for fork-lift tines.

The circulating-system filter and differential pressure gauge are mounted behind the ultrasonic-cleaner cabinets. Manual shut-off valves are provided near the filter location to permit a choice of installing or omitting a filter.

A cabinet-length fluorescent light set beneath the control panel of each cabinet provides adequate illumination for the operator.

FACILITY IMPLEMENTATION

The cleaning procedure and system requirements were approved by OCAMA and OSU together with the recommendations from specific equipment manufacturers. Ultrasonic cleaners manufactured by the Westinghouse Electric Corporation are selected. These ultrasonic units have 70 per cent of the wash-tank bottom covered by transducers and are powered by solid-state generators. OSU engineers compared the cleaning capacity of the Westinghouse ultrasonic cleaners with other units and found it to be equivalent. The 20 KC generator in the selected cleaner produces an intensity of 11.9 watts per square inch into the transducers. Requlated from the control panel, a thermostatically controlled heater with a temperature range of 50° to 250° F. provides a rapid temperature rise in the $10\frac{1}{2}$ inch wide, 14 inch deep, and 21 inch long wash tanks. Mounted in a compartment on the side of the wash tank is the heater and thermostatic sensing bulb. Inlet and drain fittings are furnished in the wash tanks. Included with the tank assembly is a forced-draft ventilation system to be mounted beneath each transducer area. Protection against heater overload is provided by a thermal cutout switch installed in the heater circuit. Set at 25° to 35° F. above normal working temperatures, the thermal overload device opens the circuit if abnormal conditions, such as the fall of liquid level below that of

the heating elements, occur. A neon pilot light glows on the ultrasonic control panel whenever the cutout switch is open.

The chemical flow systems for all of the ultrasonic cabinets are alike. Consisting of two ultrasonic wash tanks, appropriate outlets for two 55 gallon storage barrels, pump, filter or connections for a filter, and required valves, the system transfers the chemicals between the wash tanks and the barrels. Driven by a two speed pump and directed by pushbutton-operated valves, the cleaning media are transferable between any two vessels in the system. Two-way ball valves, piloted by pneumatic solenoid valves are installed in the chemical flow system on the drain-side and fill-side of each barrel and each ultrasonic cleaner. Three additional valves give a choice of "filter" or "no-filter" use. All valves operate at 100 psi. of air, to be supplied by OCAMA.

When all other valves close, the by-pass valve of the pump automatically opens, preventing pressure build-up from the turbine-type pump. Fluid can be circulated at 5 gal./min. or 20 gal./min., depending upon the vessel being filled.

Upstream from all vessels in the trichloroethylene system is a .5 micron nominal filter with removable cartridge. The dirt capacity of the filter cartridge is approximately 14 lbs. of contaminant. No maximum contamination level was specified for the orthodichlorobenzene; however, some contaminant can be removed by sedimentation. Chemicals from one barrel can be used while the other is filtering.

Selected to conform to the ultrasonic-cleaning washtanks, the internal working dimensions for the rinse tank and the dryer are each

$10\frac{1}{2}''$ x 21" x 18" deep. Any element that will fit into the wash tanks can be rinsed and dried in these units.

A minimum of 12 gallons a minute of spray is available, at 40 psi in the rinse tank. Hot water is to be supplied by OCAMA. A pushbutton operated solenoid valve controls the water supply, or the water supply can be cut off by an interlock switch activated by the hinge lid of the rinse tank.

Filtered air is drawn into the dryer chamber at 350 cfm by a 14" fan blade. Thermostatically controlled heaters maintain a constant temperature in the range of 150° to 200° F. in the dryer. An interlock switch in the lid of the dryer prevents operation of the dryer when the lid is open. Provisions have been made for mounting a precipitron on the fresh air side of the dryer, if it is desirable.

CONTROL PANEL

Each cabinet in the ultrasonic cleaning facility designed for OCAMA by OSU has its own integrated, independently operating control panel. Located within arm's reach above the work table, the vertical panel concentrates in one console all the controls of the unit. These panels are identical on the three ultrasonic-cleaner units, with appropriate differences in the panel layout of the rinse-dryer unit.

On the controls procedure, it might be pointed out that the exhaust fan in each ultrasonic unit is activated both manually and automatically; but the unit cannot be run without the fan. This precaution was incorporated by OSU engineers to reduce unnecessary fumes. The fan starts whenever either of its two sonic generators or the pump circulating the cleaning fluid is energized. The fan also may be operated by pushbutton.

The circulating system offers maximum choice of flow. By activating various combinations of buttons, the operator of a unit can pump fluid from barrel to barrel, cleaner to cleaner, barrel to cleaner, or cleaner to barrel. The pushbutton-controlled valves at all points are actuated by compressed air. There are separate suction and discharge buttons for each tank and each barrel in the unit, "yes" and "no" buttons for use of the filter, and high and low-speed buttons for the pump.

The operator must select one and only one button from each group of buttons.

Another safety factor, designed to minimize operator spillage, lies in the tank-filling controls: the operator must keep his finger on the low-speed pump button when filling an ultrasonic-cleaner tank from a barrel, although this button is interlocking when the flow is into the barrels. The high-speed button, will operate when cleaning chemicals are directed into the barrels, or when the chemicals are pumped from an ultrasonic cleaner tank and back into the same tank to filter the cleaning chemical.

If the operator selects an incompatible combination of buttons for the circulating system, the pump won't start, for example: selecting suction-"barrel-1," discharge-"tank-1," filter-"no," and pump-"hi-speed." In this case, the system is inoperative because the pump will not operate at high speed during barrel-to-tank filling process. Before it will, the operator must push the stop-reset button, which will then cancel all buttons of the circulation system, and start the selection over. The sequence in which buttons of the system are pushed is immaterial.

The matching controls for the two ultrasonic cleaners in each unit are located at left and right in the bottom row on the panel. The on and off switches for each generator can be used independently of, or in conjunction with, the timers, which are activated by a separate timer-reset pushbutton. To measure the wash cycle, the timer indicator is hand-set for the desired cleaning time, and the timer button is pushed. In subsequent cycles, when the timer-reset button is pushed,

the timer indicator automatically reverts to the originally selected time and again measures the same cycle.

The heater for each ultrasonic cleaning unit is turned on by pushbutton and controlled by a manually set thermostat.

The control panel includes pilot lights for all switches and one for the power supply.

The control panel of the rinser and dryer groups the controls for the rinse tank on the left side of the panel and the dryer controls on the right side.

The rinse water can be turned off and on by pushbutton; or the timer can easily be set to measure the rinse cycle automatically, once the timer-starter button is pushed. In succeeding cycles, the timer pointer need not be set unless a change in time is desired for the rinse cycle. Pushing the timer button automatically measures the preset rinse cycle.

Separate pushbuttons control the blower and heater; or an automatic reset timer limits the dryer cycles, controlling both the blower and the heater simultaneously. When activated separately, the blower must be in operation before the heater will start. A manually set thermostat controls the dryer temperature.

THE VENTILATION SYSTEM

The ventilation for the cleaning stand is designed to conform to the American Standard Safety Code for ventilation and operation of open-surface tanks, ASA-Z9.1 - 1951. The ASA code is sponsored by the American Industrial Hygiene Association, the American Society of Heating and Ventilation Engineers and the National Association of Fan Manufacturers.

The two liquids proposed for this cleaning facility are trichloroethylene and orthodichlorobenzene. Since the vapor densities of these liquids are greater than air, a lateral exhaust is employed. This also precludes drawing the vapors upward past the operator's face.

From Table 3 of ASA-Z9.1 - 1951, the minimum control velocity is 25 feet per minute.

The entire area of the counter top is considered as part of the tank surface in the calculations, to provide adequate ventilation for any liquid spilled on the counter top. The area of this exposed surface is approximately 11 square feet. The width-to-length ratio of the exposed surface is .53 . The backside of the stand acts as a vertical baffle and effectively confines the exhaust area to one quandrant about the hood.

From table 4 of ASA-Z9.1 - 1951, the minimum ventilation rate is 130 cubic feet of air per minute per square foot of tank area. The ventilation required is 11 x 130 cfm = 1430 cfm.

A 2 inch slot along the backside of the stand forms the hood opening. The air velocity through the slot is approximately 2140 feet per minute. The velocity pressure VP in inches of water = $\frac{2140}{4005}^2$ = .29. The hood entrance loss, he, equals 2.39 VP or .7 inches of water. (1).[1] Two 90° elbows connect the hood to the exhaust fan. The loss through the elbows = 2x loss factor x VP. For 10 inch diameter ducting, the velocity is 2630 feet per minute. VP = $\frac{2630}{4005}^2$ = .43 inches of water. Elbow loss = 2 x .39 x .43 = 3.4 inches of water.

Since the exhaust fan discharges into an exhaust manifold, no other loss factors are considered. The total static pressure or system resistance = .7 + .34 = 1.04 inches of water.

A fan delivering 1430 cfm at a static pressure of one inch of water is required.

Each of the ultrasonic cabinets has its own ventilation system, designed to conform to the preceding requirements for one cabinet. The three centrifugal fans are driven by explosion-proof motors.

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[1] Refers to Selected Bibliography.

CONCLUSIONS

To implement a reliable ultrasonic cleaning facility, OSU personnel have submitted to OCAMA detailed drawings of this complement. The specifications for the facility, mutually agreed upon by OSU and OCAMA, have been satisfied. Based on recent research conducted by OSU on the use of ultrasonic energy with chemical treatment, this method was deemed reliable for hydraulic component cleaning. The optimum requirements to facilitate hydraulic-component cleaning are three ultrasonic cabinets and one rinse-dryer cabinet.

A ventilation system with each ultrasonic cabinet has been provided to exhaust the fumes from the chemicals. Designed to be activated manually or automatically, the ventilation fan operates whenever a pump or sonic generator in the ultrasonic cabinet is energized.

Handling of the chemicals is reduced by a mechanically propelled flow system that conveys the cleaning solvent between the storage barrels and the ultrasonic cleaner tanks. A mandatory low pumping speed on the barrel-to-wash-tank filling phase and slightly recessed wash tanks are aimed at reducing the spillage of the chemical solvents.

Other safety precautions included in the design of the facility are mechanical interlocks mounted on all back and side panels of the cabinet and in the two hinge lids of the rinser and dryer units.

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The mechanical interlocks on the cabinet panels insure "no power" to the unit before the electrical equipment is easily accessible. All operation of the rinser and dryer ceases when either of their respective lids is opened.

Heaters are included with each ultrasonic unit. Protection against heater overload is provided by a thermal cutout switch designed to open the heating circuit if abnormal temperatures occur in the ultrasonic wash tanks.

To expedite and to facilitate the manipulation of the unit, semi-automatic controls were incorporated into the design. The electro-pneumatic valves in the chemical flow system allow programing of the solvents through the simplified plumbing circuit.

APPENDIX A

MAJOR EQUIPMENT

THE ULTRASONIC CLEANING CABINETS

Quantity/Cabinet	Description
2	Ultrasonic Cleaners (Westinghouse Model M-4000-1 with S#7505765G11, solid state generator and S#482C849 wash tank).
1	Two speed pump (Turbine-type stainless steel APCO type FZ4).
1	Ventilation fan with motor (Buffalo Forge "Baby" vent sets, fan size G, 1 hp motor, 1750 rpm).
1 (excluding the cleaner . . . using orthodichloro-benzene)	Chemical filter (.5 micron nominal HILCO filter, model F2-2 with filter-cartridge type PL-718-26).
12	Two way ball valves piloted by pneumatic solenoid valves 7 1" N.C., 4 1½" N.C., 1 1½" N.O. Nix Co operator No. 3140 valve, N.C.

THE RINSE-DRYER CABINET

Quantity/Cabinet	Description
1	Spray-rinse tank (Westinghouse S#482-C-850)
1	Dryer Chamber (Westinghouse Drawing No. 630D821

APPENDIX B

REFERENCE DRAWINGS

S-1 . . . . Isometric of OSU Filter Cleaning Stand

S-2 . . . . Frame Assembly

S-3 . . . . Front Skirt and Panel (Omit Panel for R/D)

S-4 . . . . Piping Plan and Details for Pump

S-5 . . . . Details of Light Facing and Top, Back, and

Side Panels (Omit Back for R/D)

S-6 . . . . Details of Tank Support Pieces

S-7 . . . . Exhaust Grille

S-8 . . . . Exhaust Hood

S-9 . . . . Exhaust Hood Installation

S-10 . . . . Control Panel Details

S-11 . . . . Details of Cabinet Counter Top and In-

stallation

S-12 . . . . Skid Assembly for Fan

S-13 . . . . Skid Assembly for Filter

S-14 . . . . Light Installation

S-15 . . . . Filter Piping and Installation

S-16 . . . . Transformer Installation

S-17 . . . . Control Panel Assembly

S-18 . . . . Relay Panel Board Installation

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INTERIM REPORT NUMBER 63-3
FILTER EVALUATION TESTS -I

Date: 30 January 1963

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INTRODUCTION

To obtain information pertaining to the contaminant capacity and pressure drop of specified elements, tests were performed by OSU personnel. These tests were conducted employing the OSU Filter Evaluation Stand, while relying on the recently built OSU Constant Temperature Stand to maintain stable hydraulic fluid temperatures. A hydraulic fluid flow rate of 3 gpm was sustained in the Filter Evaluation Stand during these tests.

Because an error was made in the designation of the rated flow to be utilized during the tests, OCAMA requested that OSU personnel conduct repeat tests on three aircraft filter elements. During the iterated tests, the hydraulic fluid flow in the Filter Evaluation Stand was to be maintained at 3.5 gpm.

Tests were conducted on the following filter elements:

A. At 3 gpm rated flow

    1. Aircraft F-105, filter P/N-700-E/6, Serial No. 2127, element from F-105 Integrity Program.

    2. Aircraft F-105, filter P/N-AC-2541-E4, Serial No. 4532, element from ADC Field Cleaning Activities.

    3. Aircraft F-101, filter P/N-AC-2541-E4, No Serial Number, element from ADC Field Cleaning Activities.

    4. Aircraft F-101, filter P/N-AC-2541-E4, Serial No. 1558, element from ADC Field Cleaning Activities.

B. At 3.5 gpm rated flow

    5. Aircraft F-101, filter P/N-AC-2541-E4, Serial No. 3549

    6. Aircraft F-101, filter P/N-AC-2541-E4, Serial No. 4755

    7. Aircraft F-101, filter P/N-AC-2541-E4, Serial No. 598

The results of these tests are included in this report.

TEST PROCEDURE

The filter elements selected for the first group of pressure
drop and Actual Dirt Capacity tests were obtained from Mr. Bailey.
Information received from Mr. Bailey showed that three of the ele-
ments had been cleaned by the ADC Field Cleaning Activities at
OCAMA and the fourth element had been obtained from the F-105
Integrity Program at OCAMA.   MIL-H-5606A hydraulic fluid which
has a viscosity of 10.18 centistokes at 130° F., was utilized in
the Filter Evaluation Stand during the tests. Throughout the first
group of tests, the hydraulic fluid flow rate in the OSU Filter
Evaluation Stand was maintained at 3 gpm. Pressure-drop tests were
conducted on the four elements, listed No. 1, 2, 3, and 4, in ac-
cordance with ARP-24A. Tests were continued on filters No. 1 and
No. 2 to determine their actual dirt capacity. These filters were
incrementally contaminated by injecting slurries of contaminated
hydraulic oil to the fluid upstream of the element being tested as
outlined in Project Report No. 4. The contaminate injected into
the hydraulic oil was A.C. Fine Test Dust.

To compare the effectiveness of the cleaning method employed
by the ADC Field Cleaning Activities with the OCAMA cleaning method,
Mr. Bailey immersed several pre-cleaned elements in trichloroethylene
in the ultrasonic cleaner. A gravimeter test was conducted by
Mr. Bailey on the trichloroethylene after the cleaning process.

In a separate request, OCAMA asked that OSU personnel repeat the pressure drop and Actual Dirt Capacity test on three elements while maintaining a rated flow of 3.5 gpm of hydraulic fluid in the test stand instead of 3 gpm. These elements, listed No. 5, 6, and 7 were obtained from OCAMA, and no information is available at OSU on their condition at the time the tests were performed. The tests on these elements were executed in the same manner as the previous pressure drop and Actual Dirt Capacity tests. An Actual Dirt Capacity test was conducted on element No. 5 and the initial pressure drop was measured across elements No. 5, No. 6, and No. 7.

RESULTS

During the two groups of tests, a rated flow of 3 gpm and 3.5 gpm, respectively, of hydraulic fluid was maintained. At 3 gpm the addition of .60 gms of contaminant to the hydraulic fluid increased the pressure drop across the cleaned element 54.55 psi. At the same flow rate, the pressure drop across the element from the F-105 Integrity Program increased 19.1 psi when 1.00 gms of contaminant was added to the test fluid. When the test was performed at 3.5 gpm rated flow on another element, the relief valve opened at the time .4 gms of contaminant was added to the test fluid.

An initial net pressure drop of less than 6 psi was observed across all the elements tested at 3 gpm rated flow while a maximum of 6.9 psi net-pressure drop was observed across the elements tested at 3.5 gpm rated flow.

Since the results of the gravimetric test were appropriated by Mr. Bailey, they are not included in this report.
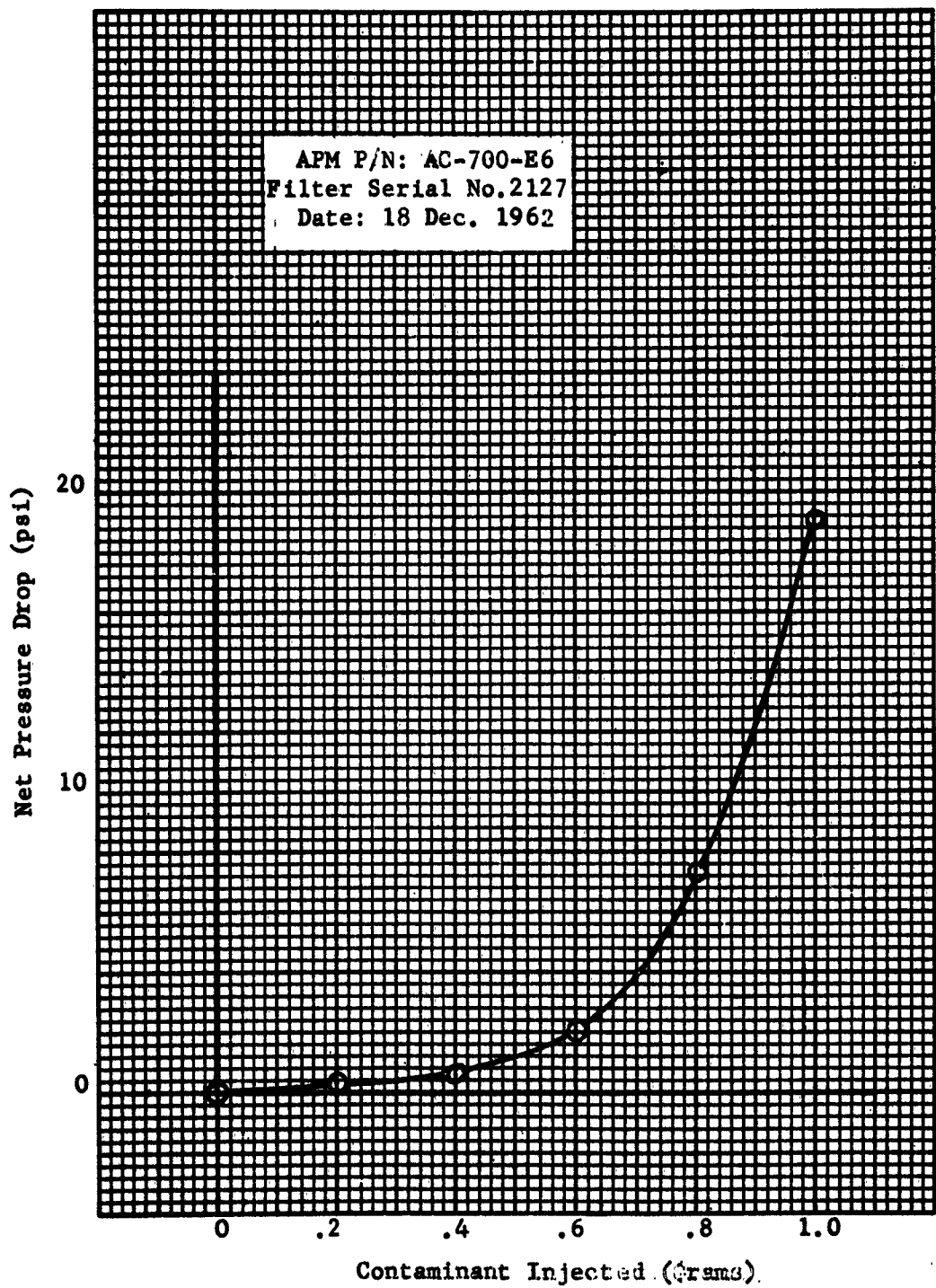
.Fig. 5-1 Contaminant Capacity Curve

5-8

Fig. 5-2 Contaminant Capacity Curve

APM P/N: AC-2541-E4
Filter Serial No.3549
Date: 18 Jan. 1963
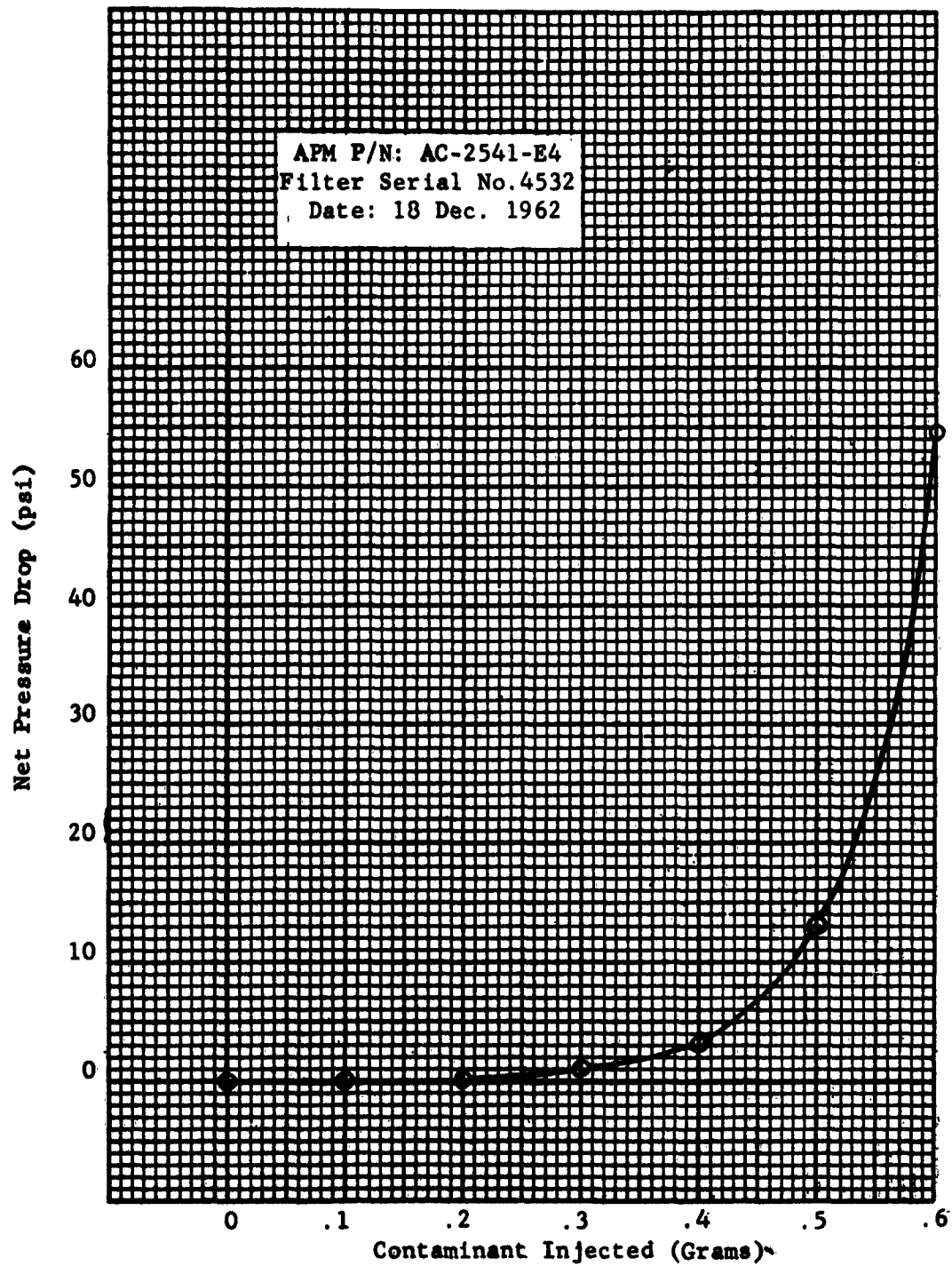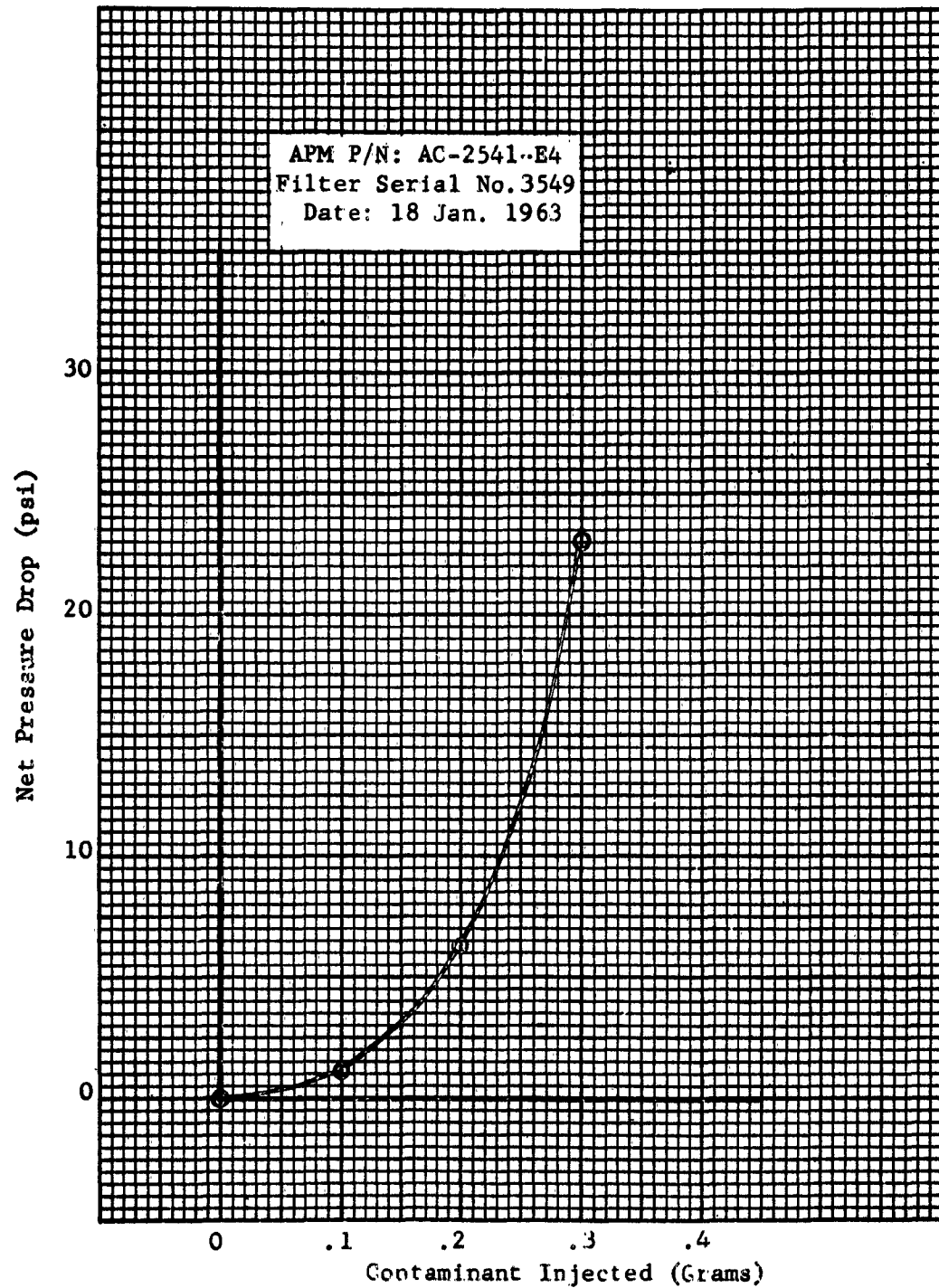
Fig. 5-3 Contaminant Capacity Curve

5-10

TABLE 5-1

FILTER DATA

FILTER P/N **AC-700-E6** AIRCRAFT **F-105** SERIAL NUMBER **2127**
NOMINAL MICRON RATING **10** RATED FLOW **3 GPM** RELIEF PRESSURE **50 PSI**
BUBBLE POINT PRESSURE **-** TEST TEMPERATURE **100°F** HOUSING TARE **5.9**

PRESSURE DROP TEST		CONTAMINANT CAPACITY TEST			
Q(GPM)	ΔP (PSI)	GRAMS	ΔP (PSI)	GRAMS	ΔP (PSI)
		0.00	6.90		
3.0	6.90	0.20	7.15		
		0.40	7.50		
		0.60	9.00		
		0.80	14.32		
		1.00	26.00		

CONTAMINANT **A.C. Fine** Date **18 December 1962**

REMARKS: **Test Witnessed by Mr. Jerry Bailey**
Element from F-105 Integrity Program
Test Conducted by Roger Tucker

TABLE 5-2

FILTER DATA

FILTER P/N AC-2541-E4 AIRCRAFT F-101 SERIAL NUMBER 4532
NOMINAL MICRON RATING 10 RATED FLOW 3GPM RELIEF PRESSURE 60 PSI
BUBBLE POINT PRESSURE - TEST TEMPERATURE 100°F HOUSING TARE 5.50

PRESSURE DROP TEST		CONTAMINANT CAPACITY TEST			
Q(GPM)	ΔP (PSI)	GRAMS	ΔP (PSI)	GRAMS	ΔP (PSI)
3 GPM	10.20	0.00	10.05		
		0.10	10.10		
		0.20	10.30		
		0.30	11.20		
		0.40	13.25		
		0.50	23.40		
		0.60	64.60		

CONTAMINANT A.C. Fine   Date 18 December 1962
REMARKS: Test Witnessed by Mr. Jerry Bailey
Elements from ADC Field Cleaning Activities
Tests Conducted by Roger Tucker

TABLE 5-3

FILTER DATA

FILTER P/N AC-2541-E4 AIRCRAFT F-101 SERIAL NUMBER No Serial No.
NOMINAL MICRON RATING 10 RATED FLOW 3 GPM RELIEF PRESSURE 60 PSI
BUBBLE POINT PRESSURE ‾ TEST TEMPERATURE 100°F HOUSING TARE 5.50

PRESSURE DROP TEST		CONTAMINANT CAPACITY TEST			
Q(GPM)	ΔP (PSI)	GRAMS	ΔP (PSI)	GRAMS	ΔP (PSI)
3.0	10.10				

CONTAMINANT _____ Date 18 December 1962
REMARKS: Test Witnessed by Mr. Jerry Bailey
Element from ADC Field Cleaning Activities
Test Conducted by Roger Tucker

TABLE 5-4

FILTER DATA

FILTER P/N AC-2541-E4 AIRCRAFT F-101 SERIAL NUMBER 1558
NOMINAL MICRON RATING 10 RATED FLOW 3 GPM RELIEF PRESSURE 60 PSI
BUBBLE POINT PRESSURE - TEST TEMPERATURE 100°F. HOUSING TARE 5.50

PRESSURE DROP TEST		CONTAMINANT CAPACITY TEST			
Q(GPM)	ΔP(PSI)	GRAMS	ΔP(PSI)	GRAMS	ΔP(PSI)
3.0	11.30				

CONTAMINANT _____ Date 18 December 1962
REMARKS: Test Witnessed by Mr. Jerry Bailey
Element from ADC Field Cleaning Activities
Test Conducted by Roger Tucker

TABLE 5-5

FILTER DATA

FILTER P/N AC-2541-E4 AIRCRAFT F-101 SERIAL NUMBER 3549

NOMINAL MICRON RATING 10 RATED FLOW 3.5 GPM RELIEF PRESSURE 50±5

BUBBLE POINT PRESSURE TEST TEMPERATURE 100°F HOUSING TARE 7.70 PSI

PRESSURE DROP TEST		CONTAMINANT CAPACITY TEST			
Q (GPM)	ΔP (PSI)	GRAMS	ΔP (PSI)	GRAMS	ΔP (PSI)
3.5	14.60	0	14.60		
		0.1	15.80		
		0.2	20.85		
		0.3	37.60		
		0.4	Relief		

CONTAMINANT A.C. Fine Date 18 January 1963

REMARKS: Tests conducted by Roger Tucker

TABLE 5-6

FILTER DATA

FILTER P/N AC 2541-E4 AIRCRAFT ___F-101___ SERIAL NUMBER ___4755___

NOMINAL MICRON RATING___10___ RATED FLOW_3.5 GPM_RELIEF PRESSURE___-___

BUBBLE POINT PRESSURE___-___TEST TEMPERATURE_100°F_, HOUSING TARE___7.70___

PRESSURE DROP TEST		CONTAMINANT CAPACITY TEST			
Q(GPM)	ΔP(PSI)	GRAMS	ΔP(PSI)	GRAMS	ΔP(PSI)
3.5	13.7				

CONTAMINANT _A.C. Fine_ Date _18 January 1963_

REMARKS: _Tests conducted by Roger Tucker_

TABLE 5-7

FILTER DATA

FILTER P/N AC 2541-E4 AIRCRAFT F-101 SERIAL NUMBER 598
NOMINAL MICRON RATING 10 RATED FLOW 3.5GPM RELIEF PRESSURE 50 ± 5 PSI
BUBBLE POINT PRESSURE - TEST TEMPERATURE 100°F. HOUSING TARE 7.70

PRESSURE DROP TEST		CONTAMINANT CAPACITY TEST			
Q(GPM)	ΔP (PSI)	GRAMS	ΔP (PSI)	GRAMS	ΔP (PSI)
3.5	14.10				

CONTAMINANT A.C. Fine   Date 18 January 1963
REMARKS: Tests conducted by Roger Tucker

INTERIM REPORT 63-4
THE AUTOMATIC FLUID TEMPERATURE CONTROLLER

Ref: Contract AF 34(601)14090
       Order Number 63-3

Date: 25 March 1963

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INTRODUCTION

In an effort to increase the accuracy of Aircraft Filter Evalua-
tion tests for OCAMA, the Filter Evaluation Laboratory of Oklahoma
State University has designed and constructed an Automatic Fluid
Temperature Controller. The increasing temperatures of the test fluid
have posed a problem, a condition that was only partly solved by the
manual adjustment of the flow rate of a coolant (water) through a heat
exchanger.

In any fluid circulation system, the heat generated by the molec-
ular friction of the fluid causes inconsistencies of the fluid viscos-
ity. This is undesirable in the Filter Evaluation test system. The
direct relationship between viscosity and temperature, combined with
the availability of temperature-measuring equipment, makes temperature
measurement an indispensable factor in test observations.

To standardize the tests utilizing the OSU Filter Evaluation
Stand, either the data must be altered to compensate for the tempera-
ture deviation, or some means must be found to repress the rising
temperatures. The calculations involved in obtaining congruent data
often have proved tedious and subject to human error; therefore, an
instrument to maintain automatic uniformity of test temperatures was
desired.

Since the tests employing the Filter Evaluation Stand are con-
ducted above room temperatures, it was deemed feasible to design and

6-3

fabricate a controlling unit to preheat the test fluid to test temperatures and maintain this temperature during the test period.

Although the Automatic Fluid Temperature Controller was designed primarily to be utilized with the Fluid Evaluation Stand, its use is not limited to this apparatus.

This report includes a description of the design and operation of the OSU Automatic Fluid Temperature Controller.
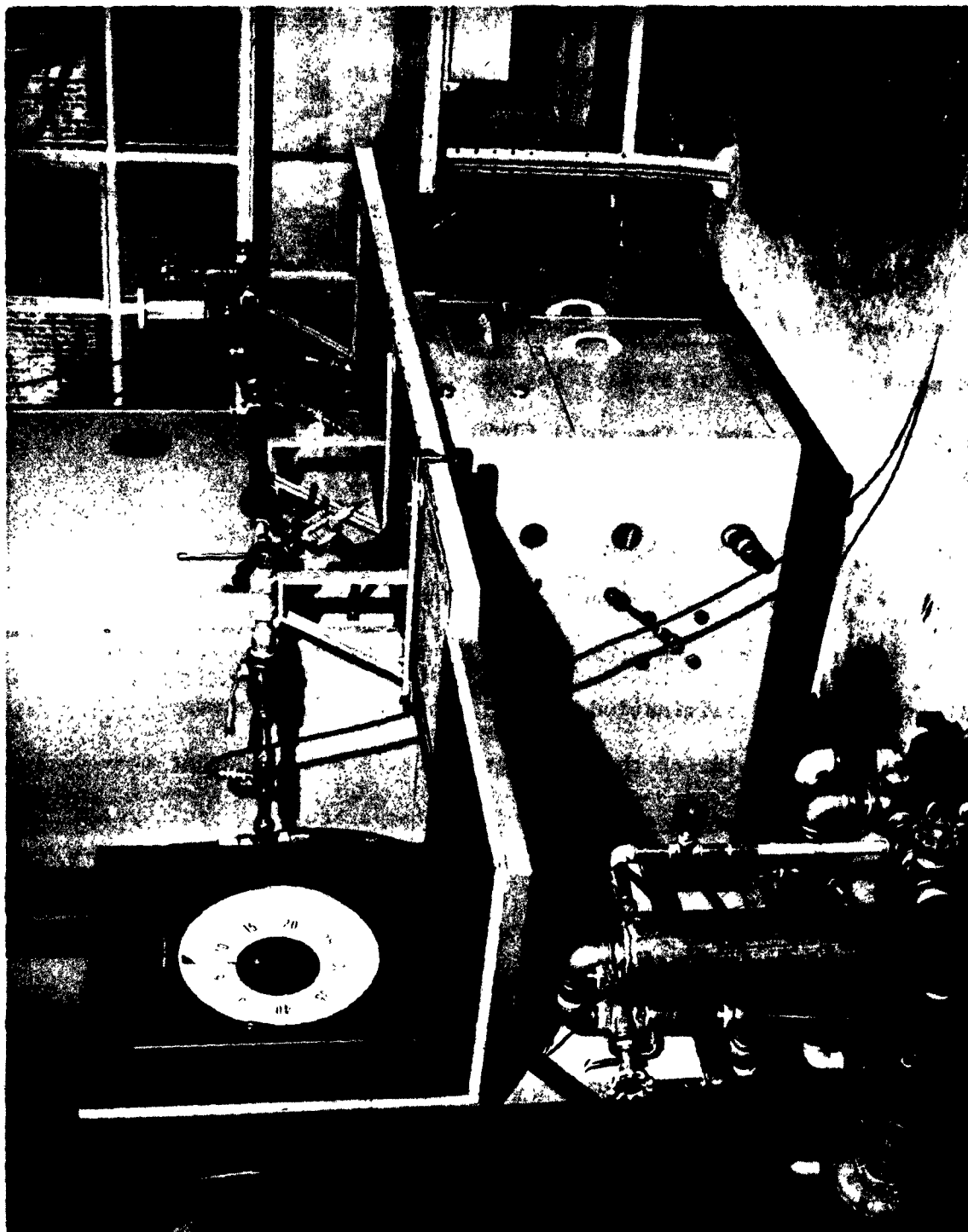
6-1. Fluid Temperature Controller.

THE TEMPERATURE-CONTROL FLUID SYSTEM

The automatic-temperature control segment of the test-fluid sys-
tem consists of a small auxiliary storage tank, a pump, heater, and
heat exchanger; Figure 6-2.

Entering the system from a laboratory storage reservoir, the test
fluid can flow through or by-pass the six-inch I.D., two and one-half
foot steel storage tank. The small fluid supply in this tank has a
dual purpose. It can be used for priming the pump and for bleeding
air from the system when a complete change of fluid is desired.
Appropriate connections and valves on the auxiliary tank allow switch-
ing of the fluid source from the laboratory storage reservoir to any
other supply, or the elimination of this tank from the system.

On the suction side of the auxiliary tank is an Oberdorfer cen-
trifugal pump. The normal operation of the temperature control system
is 10 gpm; however, this pump offers versatility in that it can deliver
up to 70 gpm when used with a less viscous system.

The heater can be operated independently, or in conjunction with
the cooling apparatus. This design was incorporated to pre-heat the
test fluid to initial temperatures and then to maintain a continuous
balance in the coolant-control mechanism during the test interval.
The heater can be turned off and on by a switch, or a timer can be
used to establish the pre-heating period. The 5000-watt elements,
housed in a two-foot long pipe, supply heat to the system.

After passing through the heater, the test fluid enters a heat exchanger. In this unit the fluid is cooled by water, the flow rate of which is automatically varied an amount proportional to the heat absorbed by the test system. The selection of the Young single-pass, type "F" counterflow heat exchanger was based on its capacity and the flow rate requirements of the stand. The mechanism controlling the water flow through the heat exchanger is discussed in the next section of this report.

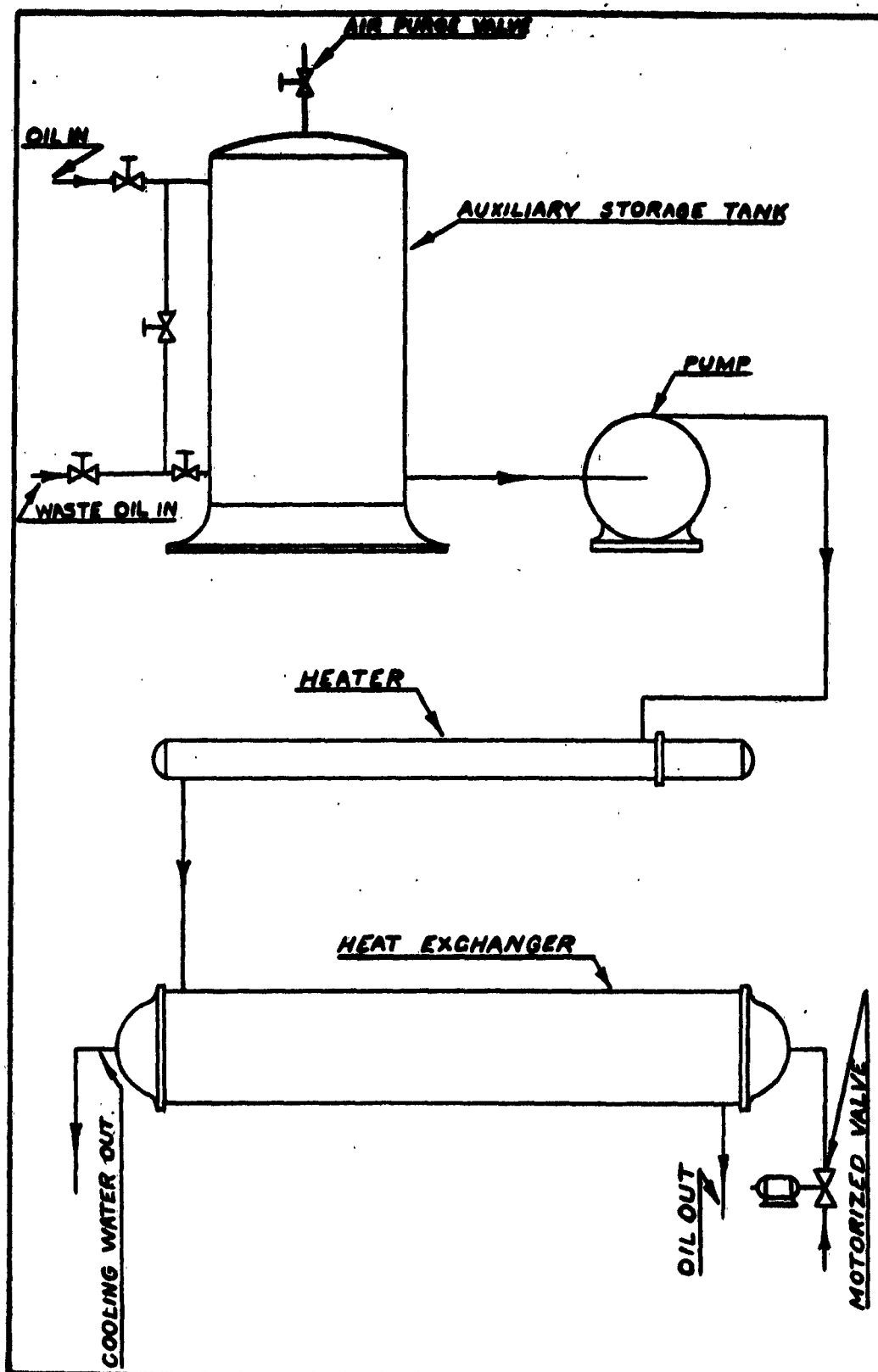The fluid is then returned to the laboratory storage reservoir, and the cycle is repeated.

Fig. 6-2. Piping Diagram for Fluid Temperature Controller.

THE COOLING SYSTEM COMPONENTS

Stabilized temperatures of the test fluid are maintained by governing the water flow through the heat exchanger. Either air or water serves satisfactorily as a cooling agent for this system since it is operated above ambient temperatures. The comparative ease of controlling the water flow and the existence of a static pressure in tap water makes water the preferred coolant in this unit.

Constant manual regulation of the water-flow through a heat exchanger has proved unsatisfactory in sustaining constant temperatures; therefore, an instrument to regulate the water rate in proportion to the temperature deviation from a standard was required.

The major components comprising the automatic control of the water are a detector, a proportioning control mechanism, and a motorized valve. Exactitude in the factory calibration between the components of the Automatic Fluid Temperature Controller is essential in attaining reliable results. The temperature indicator, pre-set to the desired test temperatures, acts as an index for the balancing operation within the water-control system. Test fluid temperatures are sensed by a detector, a thermocouple in this system, and indicated by a rotating dial on the proportioning controller. Any deviations from the pre-set temperature activates a proportioning control mechanism. Impulsively, the motorized valve is regulated, altering its position by an amount proportional to the signal received.

The thermocouple utilized in this system is a Minneapolis-Honeywell "Mego Pak" iron-constantan type, sealed in a one-sixteenth inch I.D. steel tubing. Inserted on the suction side of the auxiliary reservoir, the thermocouple measures the fluid temperature prior to its entrance into the test section.

The Brown Continuous Balance System indirectly provides both detecting and balancing of the test fluid temperatures. A dial with a rotating scale, calibrated to a range of 0 to $400°F$, records the temperature of the test fluid. The electromotive force (emf) generated by the thermocouple has a definite value for each temperature; therefore, a potentiometer in the proportioning controller can be utilized to compare the thermocouple emf with an emf equivalent to that generated by a desired temperature. The setting of the index pointer moves a contactor along a slidewire in the potentiometer. The position of the contactor along the slidewire is calibrated to produce an emf from a battery equivalent to the emf output for a definite value of temperature.

In the continuous balance system, this direct current emf differential is converted to alternating current, amplified, and hence used to drive a balancing motor. Attached to the balancing motor is a rotating scale which reports the fluid temperature.

The unbalanced emf from the proportioning controller is converted to mechanical control of the water valve by a Honeywell Electr-O-Line Control unit. In this unit, the emf is proportioned to the valve range, amplified, and with a balancing relay determining the rotation direction, operates the proportioning motor. The motor rotation adjusts the valve stem to a position comparative to the temperature

error. A Minneapolis-Honeywell model K930A valve is installed in the
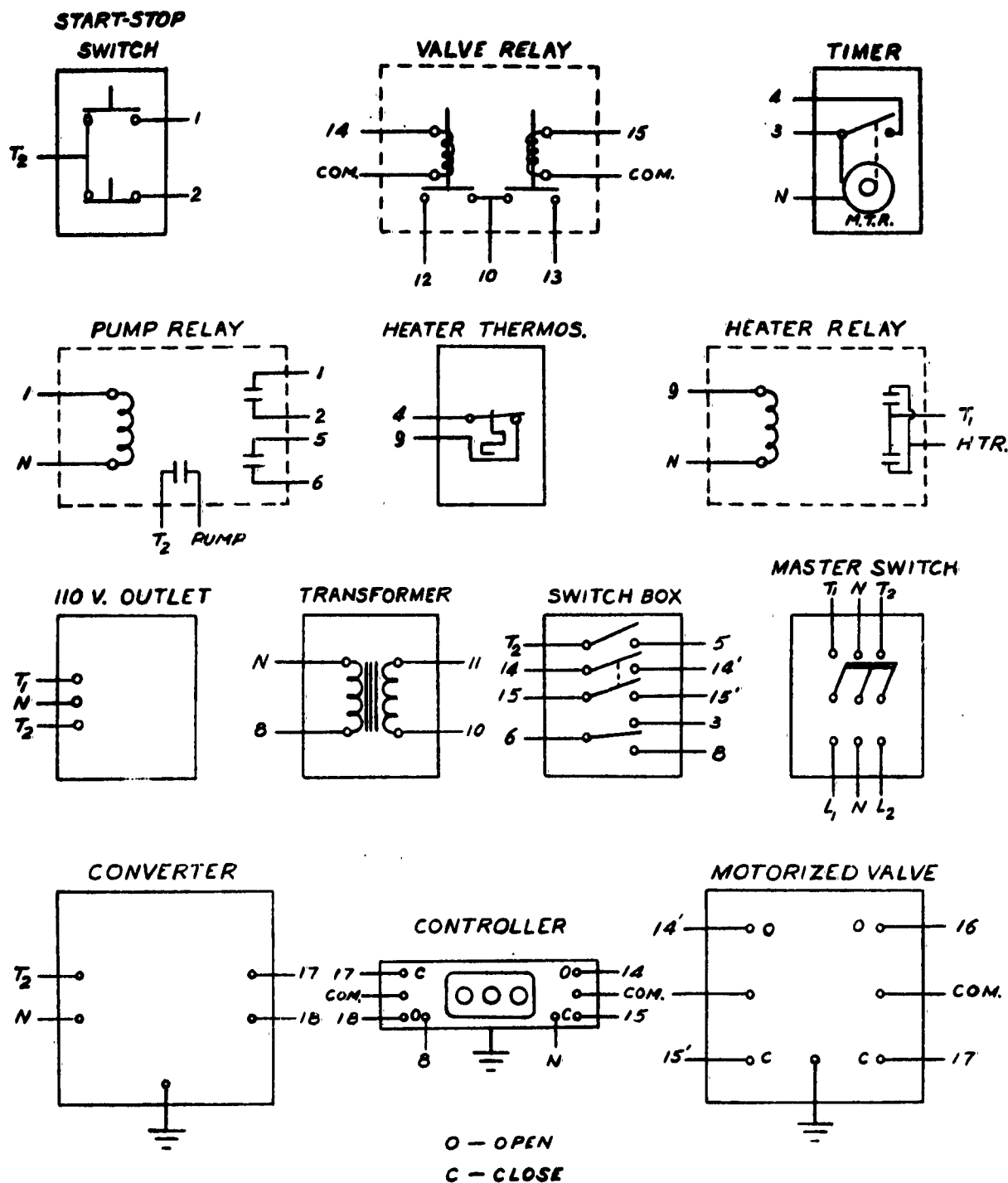water line of the heat exchanger.

START-STOP
SWITCH

VALVE RELAY

TIMER

PUMP RELAY

HEATER THERMOS.

HEATER RELAY

110 V. OUTLET

TRANSFORMER

SWITCH BOX

MASTER SWITCH

CONVERTER

CONTROLLER

MOTORIZED VALVE

O — OPEN
C — CLOSE

Fig. 6-3. Wiring Diagram for Fluid Temperature Controller.

THE OPERATION OF THE AUTOMATIC FLUID TEMPERATURE CONTROL

After turning on the power supply to the unit, sufficient time must be allowed for the test fluid to be heated to the required test temperatures. The heater can be operated by a switch, or the heating interval can be measured by a timer.

Before tests are performed, the index pointer of the automatic fluid temperature controller must be set to the desired temperature. The dial on the controller has a temperature scale which rotates as the value of the temperature changes. The fluid temperature is denoted by a stationary black triangular index at the top of the scale, while the desired temperature is signified by an adjustable index pointer which rotates with the scale.

As long as the temperature of the test fluid remains at the index setting, the stationary index and the adjustable index pointer are aligned. When the scale rotates, the proportioning control mechanism operates, adjusting the motorized valve to regulate the water flow.

THE CONSTRUCTION

The selection of the design of the Automatic Fluid Temperature Control Stand was based on economy, versatility, and simplicity of operation. Components for the unit were obtained either from the Mechanical Engineering Laboratory stock or from their respective manufacturers. All of the control components belong to the Mechanical Engineering Laboratory.

The OSU constructed one-inch-angle-iron frame is fitted with a plywood base, apron and vertical panel. A protective coating of Formica on the apron and vertical panel contributes to the protection of these sections and also to the appearance of the stand. Mounted on wheels, this unit is easily transferred to any section of the laboratory. The over-all dimensions of the temperature controller is two-feet by three-feet by six-feet high.

Most of the flow equipment is securely attached to the base of the stand. The pump and motor are provided with a special cast-iron base. This arrangement simplified the installation of the equipment and provided a low center of gravity in the stand.

Aluminum panels enclosing the equipment provide protection for the operator. Doors in these panels allow access to the valve handles.

Flush-mounted on the front panel is the easily reached dial of the control unit. The electrical control mechanisms are mounted behind this dial and at the back of the apron. The front section of the apron

provides work space for the operator. The stand is grounded and is equipped with adequate fuses for the protection of the electrical equipment.

CONCLUSIONS

The Automatic Fluid Temperature Controller is a reliable instrument for the control of test fluid temperature. This instrument reports, as well as regulates, the fluid temperatures. Observations of the test fluid temperatures during the performance of filter evaluation tests show only a one-degree variation from a standard temperature.

The test fluid temperatures can be read directly from a large, easily read dial. A heater is provided to pre-heat the test fluid and maintain a balance in the proportioning control mechanism.

The intricate water-control components are calibrated to detect any temperature deviation from a standard and to automatically correct this error. This controlling unit facilitates the regulation of the cooling agent, a contrast to the constant manual regulation previously required. To reduce the initial cost of the stand, available laboratory equipment was used whenever it was practical.

Safety for the unit operator is provided by an enclosure for all mechanical equipment and a ground for the stand. Compactness, portability, and a large volume pump contribute to the application of the Automatic Fluid Temperature Controller to other test stands.

REFERENCE

1. Instruction Manual for installation, operation, and maintenance,
   No. 15103G, Issue 2, Minneapolis-Honeywell Regulator Company,
   Brown Instruments Division.

INTERIM REPORT NUMBER 63-5
THE CLEANING FLUID STAND

Ref: Contract AF 34(601)-14090
      Order Number 63-3

Date: 26 July 1963

PROJECT PERSONNEL INVOLVED IN STUDY

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J. E. Bose	Assistant Project Leader
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INTRODUCTION

This report describes the design, construction, and capabilities
of the OSU Cleaning Fluid Stand. However, to reach a common understand-
ing of just why this stand was needed, one should review the investiga-
tions involving the application of this unit. Heretofore, the studies
on the minimization of contamination in aircraft hydraulic systems
have nucleated on the capabilities of the filter elements. Pressure
drop and contaminant capacity tests have been conducted on elements in
various stages of loading. New elements have been tested, cleaned ele-
ments have been tested, and methods of cleaning have been investigated.
Considerable progress has been made in this area, so now it is time to
go back a little and analyze the source of this unwelcome contaminant.
Since a hydraulic system is closed, there are apparently only two
sources of contamination, those built into the system or introduced
when parts or fluid is replaced and those generated by the components
in the activated system. The natural sequence to the recent filter
element investigation then, is to focus attention to other aspects of
the hydraulic system.

With methods of evaluating filter element cleanliness being fairly
well established, the need arises to find a reliable method of deter-
mining the cleanliness of other hydraulic system components, and hence
establish a criterion for their cleanability. Many of the techniques
used in evaluating filter element cleanliness are inadequate when
applied to other system components. This is because of the very nature

of the contacting surfaces of these components with the fluid system.
On some components, only the internal surfaces touch the hydraulic fluid;
on others it may be only external surfaces, and still on others, it
might be both. Small passages and moving parts differentiate and com-
plicate the problems encountered in evaluating the cleanliness of the
individual counterparts of a hydraulic system.

To start, first the solvents for reliable cleaning of the hydraulic
parts had to be selected. With the recommendations of OCAMA, two clean-
ing solvents were selected to be used in conjection with ultrasonic
equipment, Freon T.F., trade name of trichlorotrifluorethane, and Tri-
chloroethylene, O-T-643. Both solvents apparently possess the charac-
teristics essential for the cleaning of hydraulic components, for with
reasonable care they can be easily handled, distilled, or mechanically
filtered to a desired cleanliness level. In addition, they are compati-
ble with hydraulic component materials. But as past investigations have
shown, these solvents when received from their manufacturers are clean,
but not clean enough for the precision cleaning essential for an air-
craft hydraulic system. Therefore, these solvents must be filtered
before they can be used.

For the small amount of the "clean" solvents previously required,
filtration of these solvents using the Millipore apparatus was satis-
factory. A small amount of the solvent was filtered and placed in a
clean flask, and as "clean" solvent was needed, small amounts were
removed from the flask. However, with repeated openings of the flask,
there was the risk of contamination of the clean solvents and frequent
checks were required to assure its cleanliness. In addition, recovery
of solvents used for cleaning parts was poor, for these contaminated

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solvents quickly clogged the Millipore filters.

Thus, it seemed , as the scope of study on hydraulic systems widened, a means of providing large quantities of "clean" solvents was needed. So the cleaning fluid stand was designed and constructed by OSU personnel to implement the operation of obtaining large amount of reliably clean solvents.

TRICHLOROETHYLENE SYSTEM

Filtration of the trichloroethylene circulated through the Cleaning Fluid Stand is provided by mechanical filters. . A schematic diagram of this system is shown in Fig. 7-1. .

The trichloroethylene for the cleaning fluid system is stored in a steel container with a dome shaped bottom. The dome shape bottom of this reservoir allows collection of any sedimentary particles at the container outlet, whence the solvent is withdrawn through stainless steel tubing by an electric-motor-driven, positive displacement pump. A relief valve included in the system prevents overloading of the pump. Operated by a switch, this pump forces the solvent through a 20 gpm Hilco P N PS-718-26 filter element which has a .5 micron nominal rating. The flow rate maintained in the stand is one gal/min.

The Hilco filter is housed in a steel shell, eight-inches in diamter. Valves located at the inlet and outlet of this housing permits segregation and removal of the filter housing without excessive spillage of the solvent. Removable end fittings on the filter housing allow access to the replaceable filter cartridge, and cleaning of the housing. The brass valves contain Teflon seats, which are compatible with the solvent in the system and which prevent metal-to-metal grinding in the valves and the consequent generation of contaminant.

Exuding from the filter, the solvent traces one of two paths, selected by the operator of the stand. Manually operated valves govern the circuit of the operating system. The solvent may be returned to the

storage tank, recirculated and consequently multiple filtered. Or as an alternative, solvent passes to a dispensing tube from which the desired amount of trichloroethylene can be withdrawn and the overflow returned to the storage tank through a basin mounted beneath this spout. This basin also provides a convenient inlet for adding solvent to the otherwise closed system.

For reagent cleanliness, three in-line Millipore filters are included in the sytem; however, these filters are by-passed during normal operation of the system.

Although the system was designed primarily for the filtration of trichloroethylene, conceivably a replacing of the filter and flushing of the system could make it applicable for the recovery of other solvents which are compatible with the filter, filter housing, and pump.
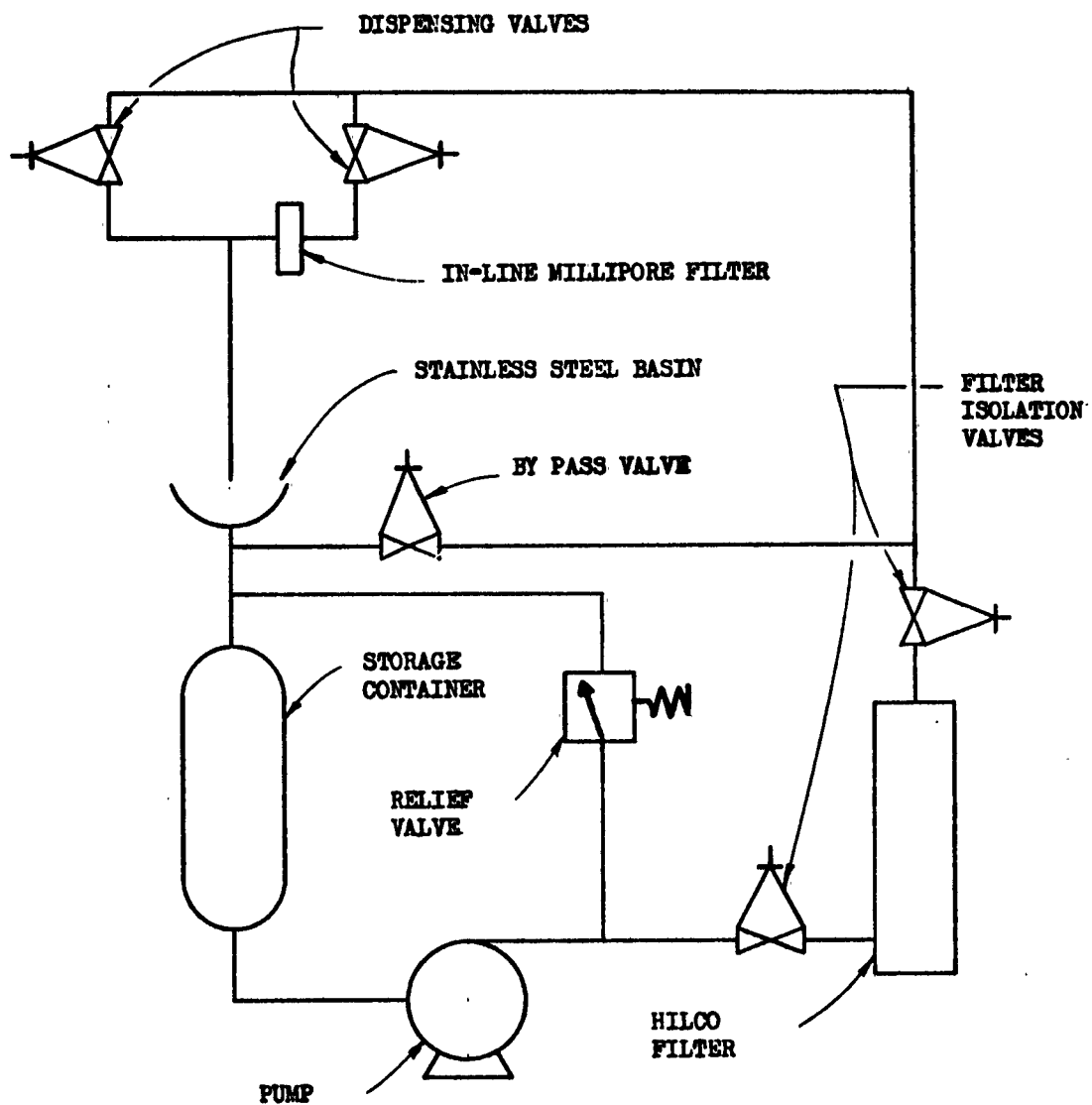
DISPENSING VALVES

IN-LINE MILLIPORE FILTER

STAINLESS STEEL BASIN

FILTER ISOLATION VALVES

BY PASS VALVE

STORAGE CONTAINER

RELIEF VALVE

HILCO FILTER

PUMP

Fig. 7-1. Schematic Diagram for Trichloroethylene Clean-up System.

FREON T. F. SYSTEM

Freon T. F. is customarily recovered by distillation because it possesses chemical properties compatible with this mode of contaminant extraction. With a vaporization temperature of 117.6°F, as well as chemical stability at this slightly elevated temperature, Freon T. F. can easily be distilled to yield the solvent relatively free of extraneous particles. The distiller selected and described in this section is manufactured by G. S. Blakeslee and Company of Chicago, Illinois. A schematic diagram of the Freon T. F. recovery system to be used in the OSU Cleaning Fluid Stand is shown in Fig. 7-2.

Suction from a 10 gallon container serving for the storage of the used solvent is provided by an electrically-powered centrifugal pump. The solvent is transferred to the distillation apparatus and heated by a 110 volt, single phase, electrical, oil immersion heater. As a safety device, a vapor-control thermostat regulates the heater to assure that no overheating in the distiller occurs, turning off the heater whenever a pre-set maximum temperature is detected. The emitting vapors from the solvent accumulating at the top of the still are cooled, and consequently condensed, by a tap-water fed cooling jacket. The drippings of the condensed fluid then collect on sloping trays which feed to the still outlet. Further cooling of the solvent is provided by a solvent cooler before the Freon T. F. flows to a clean storage container. The distillation apparatus has a capability of two gallons of Freon distillation per hour and is fabricated of 16 gauge, type 316, stainless steel

welded construction with a removable top. Features also include a dial type thermometer and a liquid level gauge.

This distiller is mounted above the Cleaning Fluid Stand. Consequently, because of the relative positions of the still and stand, the solvent egresses from a dispensing tube on the stand whenever an intervening valve is opened. Beneath the dispensing tube mounted in the cleaning fluid cabinet is a small stainless steel basin. Thus, any spilled fluid is caught by the basin and returned to the used solvent cleaner container located underneath the basin drain.

While the distillation apparatus was primarily purchased for the distillation of the Freon, it is also capable of trichloroethylene distillation. Therefore, a comparison between the recoverability of trichloroethylene by distillation and filtration can be made.
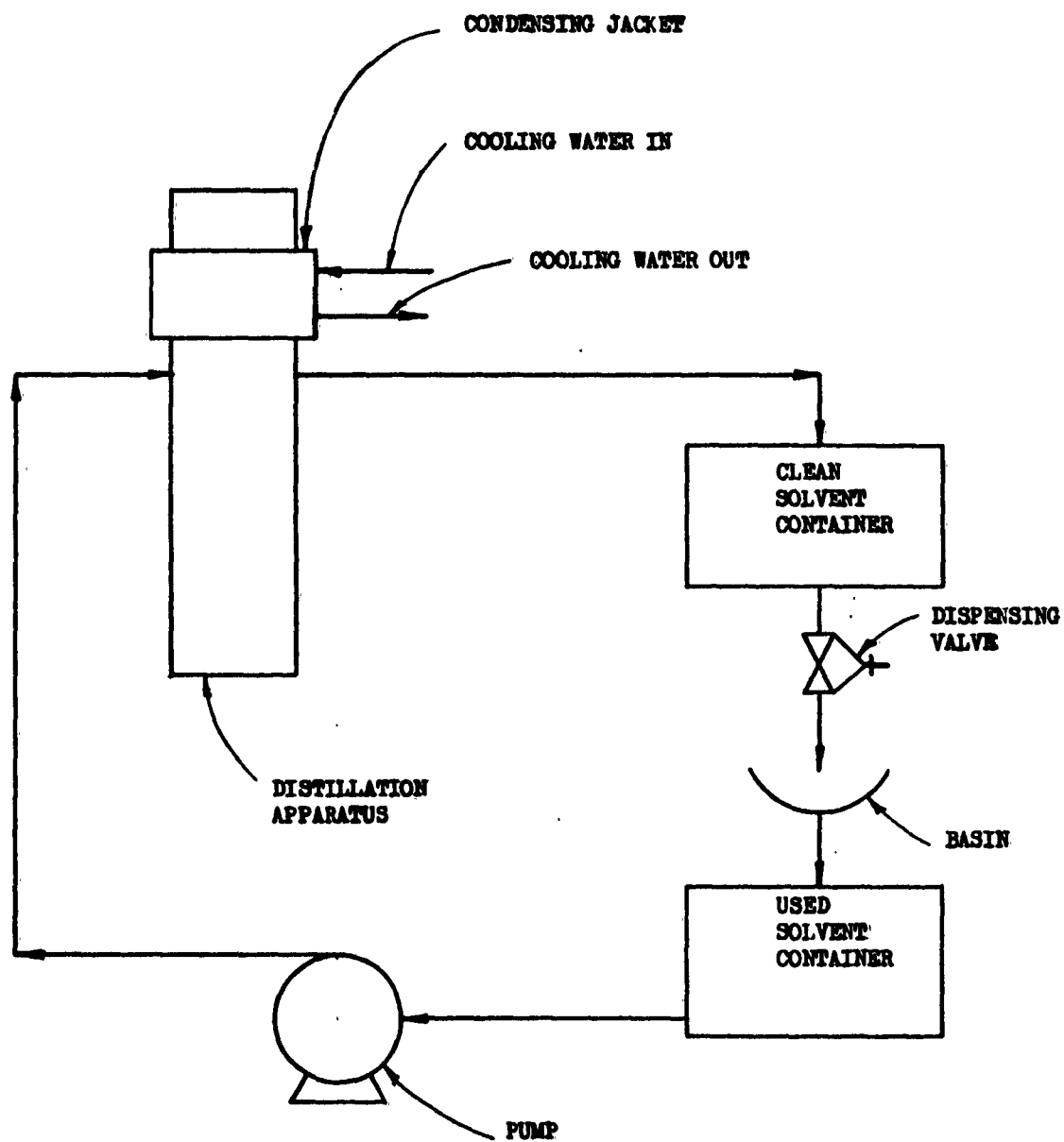
Fig. 7-2. Schematic Diagram for Freon T. F. Solvent Clean-up System.

THE CABINETS

The cabinet of the OSU constructed Cleaning Fluid Stand was designed to match other cabinets in the Filter Evaluation Laboratory. A sketch of the solvent dispensing cabinet is shown in Fig. 7-3. Erected of a wooden frame covered with 3/4-inch plywood, the 42-inch long portable cabinet displays a work area decked with easily cleaned white Formica. Sunken into the work counter are two ten-inch diameter stainless steel basins, each composing a component of the two systems of the unit. Overhanging each basin is a dispensing tube, one for trichloroethylene and the other for Freon. Thus, the clean solvents are available in a manner similar to hot and cold water at a sink.

All controls for the unit are mounted on the small vertical panel protruding from the top rear of the unit. Both Freon T. G. and tri- chloroethylene are dispensed from the cabinet. The left half is for Freon, the right half for trichloroehtylene. The complete trichloro- ethylene recovery system is housed within the cabinet; however, only the storage tank, pump, and dispensing valve and tube of the Freon T. F. system is enclosed within the unit--the distillation apparatus and clean solvent container being mounted on the wall above the cabinet to pro- vide gravity pressure to the Freon system.

Placards attached to the appropriate controls provide identification for the operator of the stand. Doors on the front of the portable cab- inet allow access to the solvent storage tanks and pumps enclosed by the stand.
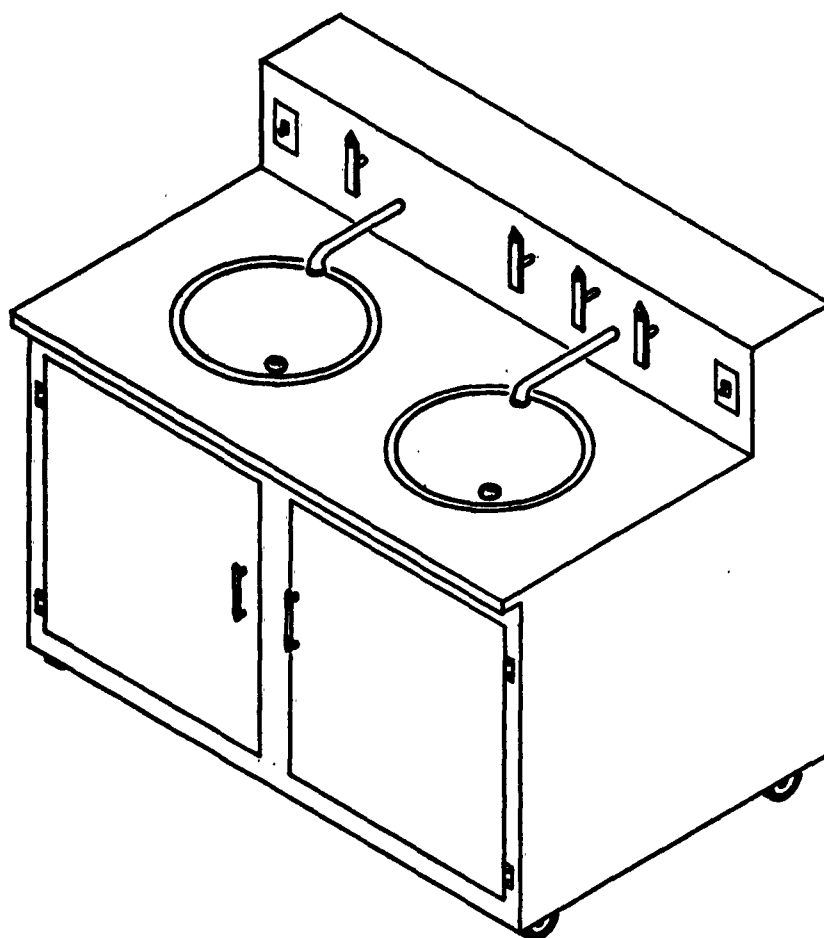
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Fig. 7-3.   Solvent Dispensing Cabinet.

EVALUATING THE CLEANING FLUID STAND

In order to determine the amount of contaminant rejected to the cleaning solvents during the ultrasonic cleaning of hydraulic components, it was first necessary to establish the contaminant level of the solvents prior to their use. At the same time, this study enabled OSU personnel to effectively evaluate the capabilities of the Cleaning Fluid Stand.

Since a commercial distillation apparatus was not available at the time tests were performed, a laboratory distiller was improvised for the recovery of Freon T. F. and trichloroethylene. The all-glass distiller includes a detachable flask, which contains the solvent to be recovered. Heat is applied to this flask by an electric heater. Fumes from the boiling solvent are collected and cooled by a water-fed, cork-screw condenser from which the sequential condensate egresses to a clean glass receptacle. The only control on the heater is an "off-on" switch; consequentially, there is no automatic protection against overheating this distillation apparatus. Thus, a disadvantage to this unit is the need for constant attention. Leakage from the joints of the distiller are reduced by wrapping the joints with Teflon tape. A laboratory-devised precaution against airborne contamination collecting in the distilled solvent is provided by a piece of Saran Wrap enveloping the opening between the condenser outlet and the clean solvent receptacle.

Trichloroethylene was obtained from OCAMA and stored in closed containers. The Freon T. F. was purchased from its manufacturer.

Samples of the trichloroethylene "as received" were drawn from the container by a pipette, to eliminate any foreign particles that might be introduced into the solvent if poured from the container. Careful handling of the solvent and clean, capped, sampling bottles were emphasized throughout these tests to minimize the accumulation os airborne contaminant in the samples.

Other samples of the trichloroethylene were obtained from the Cleaning Fluid Stand, with and without Millipore filtration, and from the distillation apparatus. Samples of distilled and "as received" Freon T. F. were also collected for observation.

Calibrated for counts of 5, 10, 20, and 40 micron particles, a HIAC particle counter was utilized to evaluate the contaminant in each of the aforementioned samples. Difficulty was encountered in obtaining congruent particle counts on duplicate samples, until it was theorized that the cause of the deviation was due to vaporization of the solvents by the heat emitted from the particle counter. Therefore, a cooling system was devised to cool the solvents prior to their entrance into the particle counters. This apparently solved the difficulty. Gravimetric tests were also conducted on some of the samples of the test data. Examples are shown in tables following this section, and for easy comparison are included in graphs, Figs. 7-4 and 7-5.

TABLE 7-1

FILTER EVALUATION LABORATORY
OKLAHOMA STATE UNIVERSITY
FLUID CONTAMINANT ANALYSIS

ORIGIN OF SAMPLE Trichloroethylene In As Received Condition

TEST CONDUCTED BY OSU DATE 7 June 1963 TYPE OF FLUID Trichloroethylene

PARTICLE COUNT ANALYSIS

METHOD OF SAMPLING Bottle PHOTO TUBE CURRENT 100 Microamps
TEST FLOW RATE 60 Drops Per Min. TEST VOLUME 5 ml.

PARTICLE DIAMETER (µ)	PARTICLES ABOVE SPECIFIED DIAMETER			
	TEST 1	TEST 2	TEST 3	AVERAGE
5	800	790		795
10	106	326		216
20	10	32		21
40	2	3		3

REMARKS

GRAVIMETRIC ANALYSIS

WEIGHT OF FILTER PAD AND CONTAMINANT _____ 91.6 mg
WEIGHT OF DRY FILTER PAD _____ 91.3 mg
WEIGHT OF CONTAMINANT _____ 0.3 mg
TARE WEIGHT OF TEST FLUID _____ 0.2 mg
CORRECTED CONTAMINANT WEIGHT _____ 0.1 mg
VOLUME OF FLUID TESTED _____ 100 ml.
GRAVIMETRIC ANALYSIS RESULTS (mg/liter) _____ 1.0 mg/liter
REMARKS

TABLE 7-2

FILTER EVALUATION LABORATORY
OKLAHOMA STATE UNIVERSITY
FLUID CONTAMINANT ANALYSIS

ORIGIN OF SAMPLE _Filter Stand Without Millipore Filtration_

TEST CONDUCTED BY _OSU_ DATE _11 June 1963_ TYPE OF FLUID _Trichloroethylene_

PARTICLE COUNT ANALYSIS

METHOD OF SAMPLING _Bottle_ PHOTO TUBE CURRENT _100 Microamps_
TEST FLOW RATE _60 Drops Per Min._ TEST VOLUME _5 ml._

PARTICLE DIAMETER (µ)	PARTICLES ABOVE SPECIFIED DIAMETER			
	TEST 1	TEST 2	TEST 3	AVERAGE
5	891	902	818	870
10	175	127	81	128
20	34	12	8	18
40	3	2	1	2

REMARKS

GRAVIMETRIC ANALYSIS

WEIGHT OF FILTER PAD AND CONTAMINANT _101.18 mg_
WEIGHT OF DRY FILTER PAD _96.0 mg_
WEIGHT OF CONTAMINANT _5.23 mg_
TARE WEIGHT OF TEST FLUID _3.74 mg_
CORRECTED CONTAMINANT WEIGHT _1.49 mg_
VOLUME OF FLUID TESTED _1 Liter_
GRAVIMETRIC ANALYSIS RESULTS (mg/liter) _1.49 mg/Liter_

REMARKS

TABLE 7-3

FILTER EVALUATION LABORATORY
OKLAHOMA STATE UNIVERSITY
FLUID CONTAMINANT ANALYSIS

ORIGIN OF SAMPLE _Filter Stand With Millipore Filter (One)_

TEST CONDUCTED BY _OSU_____DATE _23 June 1963_ TYPE OF FLUID _Trichloroethylene_

PARTICLE-COUNT ANALYSIS

METHOD OF SAMPLING _Bottle_____PHOTO TUBE CURRENT _50 Microamps_

TEST FLOW RATE _60 Drops Per Min._ TEST VOLUME _5 ml._

PARTICLE DIAMETER (µ)	PARTICLES ABOVE SPECIFIED DIAMETER			
	TEST 1	TEST 2	TEST 3	AVERAGE
5	111	180		145
10	18	39		29
20	1	3		2
40	0	1		1

REMARKS _____

GRAVIMETRIC ANALYSIS

WEIGHT OF FILTER PAD AND CONTAMINANT_____ _100.18 mg_

WEIGHT OF DRY FILTER PAD _____ _94.75 mg_

WEIGHT OF CONTAMINANT_____ _5.43 mg_

TARE WEIGHT OF TEST FLUID_____ _5.00 mg_

CORRECTED CONTAMINANT WEIGHT_____ _.43 mg_

VOLUME OF FLUID TESTED_____ _1 Liter_

GRAVIMETRIC ANALYSIS RESULTS (mg/liter)_____ _.43 mg/Liter_

REMARKS _____

TABLE 7-4

FILTER EVALUATION LABORATORY
OKLAHOMA STATE UNIVERSITY
FLUID CONTAMINANT ANALYSIS

ORIGIN OF SAMPLE __FILTER STAND WITH__
__TRIPLE MILLIPORE FILTRATION__
TEST CONDUCTED BY __OSU__ DATE __22 July 1963__ TYPE OF FLUID __TRICHLOROETHYLENE__

PARTICLE COUNT ANALYSIS

METHOD OF SAMPLING __BOTTLE__ PHOTO TUBE CURRENT __50 MICROAMP__
TEST FLOW RATE __60 DROPS PER MIN.__ TEST VOLUME __5 ml__

PARTICLE DIAMETER (µ)	PARTICLES ABOVE SPECIFIED DIAMETER			
	TEST 1	TEST 2	TEST 3	AVERAGE
6	50	58	59	56
10	12	15	11	13
20	2	0	1	1
40	0	0	1	0

REMARKS

GRAVIMETRIC ANALYSIS

WEIGHT OF FILTER PAD AND CONTAMINANT
WEIGHT OF DRY FILTER PAD
WEIGHT OF CONTAMINANT
TARE WEIGHT OF TEST FLUID
CORRECTED CONTAMINANT WEIGHT
VOLUME OF FLUID TESTED
GRAVIMETRIC ANALYSIS RESULTS (mg/liter)
REMARKS

7-19

TABLE 7-5

FILTER EVALUATION LABORATORY
OKLAHOMA STATE UNIVERSITY
FLUID CONTAMINANT ANALYSIS

ORIGIN OF SAMPLE _DISTILLED TRICHLOROETHYLENE_

TEST CONDUCTED BY _OSU_ DATE _26 JUNE 1963_ TYPE OF FLUID _TRICHLOROETHYLENE_

PARTICLE COUNT ANALYSIS

METHOD OF SAMPLING _BOTTLE_ PHOTO TUBE CURRENT _50 MICROAMPS_

TEST FLOW RATE _60 DROPS PER MIN._ TEST VOLUME _5 ml._

PARTICLE DIAMETER (μ)	PARTICLES ABOVE SPECIFIED DIAMETER			
	TEST 1	TEST 2	TEST 3	AVERAGE
6	169	169		169
10	43	32		38
20	1	4		3
40	0	0		0

REMARKS _____

GRAVIMETRIC ANALYSIS

WEIGHT OF FILTER PAD AND CONTAMINANT _____

WEIGHT OF DRY FILTER PAD _____

WEIGHT OF CONTAMINANT _____

TARE WEIGHT OF TEST FLUID _____

CORRECTED CONTAMINANT WEIGHT _____

VOLUME OF FLUID TESTED _____

GRAVIMETRIC ANALYSIS RESULTS (mg/liter) _____

REMARKS _____

TABLE 7-6

FILTER EVALUATION LABORATORY
OKLAHOMA STATE UNIVERSITY
FLUID CONTAMINANT ANALYSIS

ORIGIN OF SAMPLE _TRIPLE FILTERED WITH MILLIPORE FILTER_

TEST CONDUCTED BY _OSU_ DATE _20 JUNE 1963_ TYPE OF FLUID _TRICHLOROETHYLENE_

PARTICLE COUNT ANALYSIS

METHOD OF SAMPLING _BOTTLE_ PHOTO TUBE CURRENT _50 MICROAMPS_

TEST FLOW RATE _60 DROPS PER MIN._ TEST VOLUME _5 ml._

PARTICLE DIAMETER (μ)	PARTICLES ABOVE SPECIFIED DIAMETER			
	TEST 1	TEST 2	TEST 3	AVERAGE
5	98	99	83	93
10	16	27	17	20
20	1	6	1	3
40	0	2	0	1

REMARKS

GRAVIMETRIC ANALYSIS

WEIGHT OF FILTER PAD AND CONTAMINANT

WEIGHT OF DRY FILTER PAD

WEIGHT OF CONTAMINANT

TARE WEIGHT OF TEST FLUID

CORRECTED CONTAMINANT WEIGHT

VOLUME OF FLUID TESTED

GRAVIMETRIC ANALYSIS RESULTS (mg/liter)

REMARKS

TABLE 7-7

FILTER EVALUATION LABORATORY
OKLAHOMA STATE UNIVERSITY
FLUID CONTAMINANT ANALYSIS

ORIGIN OF SAMPLE *Freon T.F. Solvent In The As Received Condition*

TEST CONDUCTED BY *OSU* _____ DATE *1 July 1963* TYPE OF FLUID *Freon T.F.*

PARTICLE COUNT ANALYSIS

METHOD OF SAMPLING *Bottle* _____ PHOTO TUBE CURRENT *50 Microamps*

TEST FLOW RATE *60 Drops Per Min.* ____ TEST VOLUME ____ *5 ml.*

PARTICLE DIAMETER (µ)	PARTICLES ABOVE SPECIFIED DIAMETER			
	TEST 1	TEST 2	TEST 3	AVERAGE
6	476	432		454
10	97	86		92
20	10	9		10
40	1	3		2

REMARKS _____

GRAVIMETRIC ANALYSIS

WEIGHT OF FILTER PAD AND CONTAMINANT _____

WEIGHT OF DRY FILTER PAD _____

WEIGHT OF CONTAMINANT _____

TARE WEIGHT OF TEST FLUID _____

CORRECTED CONTAMINANT WEIGHT _____

VOLUME OF FLUID TESTED _____

GRAVIMETRIC ANALYSIS RESULTS (mg/liter) _____

REMARKS _____

TABLE 7-8

FILTER EVALUATION LABORATORY
OKLAHOMA STATE UNIVERSITY
FLUID CONTAMINANT ANALYSIS

ORIGIN OF SAMPLE ___DISTILLED FREON T.F.___

TEST CONDUCTED BY ___OSU___ DATE ___3 July 1963___ TYPE OF FLUID ___FREON T.F.___

PARTICLE COUNT ANALYSIS

METHOD OF SAMPLING ___BOTTLE___ PHOTO TUBE CURRENT ___50 MICROAMP___

TEST FLOW RATE ___60 DROPS PER MIN.___ TEST VOLUME ___5 ml___

PARTICLE DIAMETER (μ)	PARTICLES ABOVE SPECIFIED DIAMETER			
	TEST I	TEST 2	TEST 3	AVERAGE
6	20	20	21	20
10	6	4	4	5
20	0	1	0	0
40	0	0	0	0

REMARKS_____

GRAVIMETRIC ANALYSIS

WEIGHT OF FILTER PAD AND CONTAMINANT_____

WEIGHT OF DRY FILTER PAD _____

WEIGHT OF CONTAMINANT_____

TARE WEIGHT OF TEST FLUID_____

CORRECTED CONTAMINANT WEIGHT_____

VOLUME OF FLUID TESTED_____

GRAVIMETRIC ANALYSIS RESULTS (mg/liter)_____

REMARKS _____

Fig. 7-4. Particle Size Distribution for Trichloroethylene.

Origin of Sample:
    a.   Filter stand without millipore
    b.   "as received" condition
    c.   distilled
    d.   Filter stand with one (1) Millipore filter
    e.   Triple filtered with Millipore apparatus
    f.   Filter stand with three (3) Millipore filters

FLUID CONTAMINATION CHARACTERISTICS
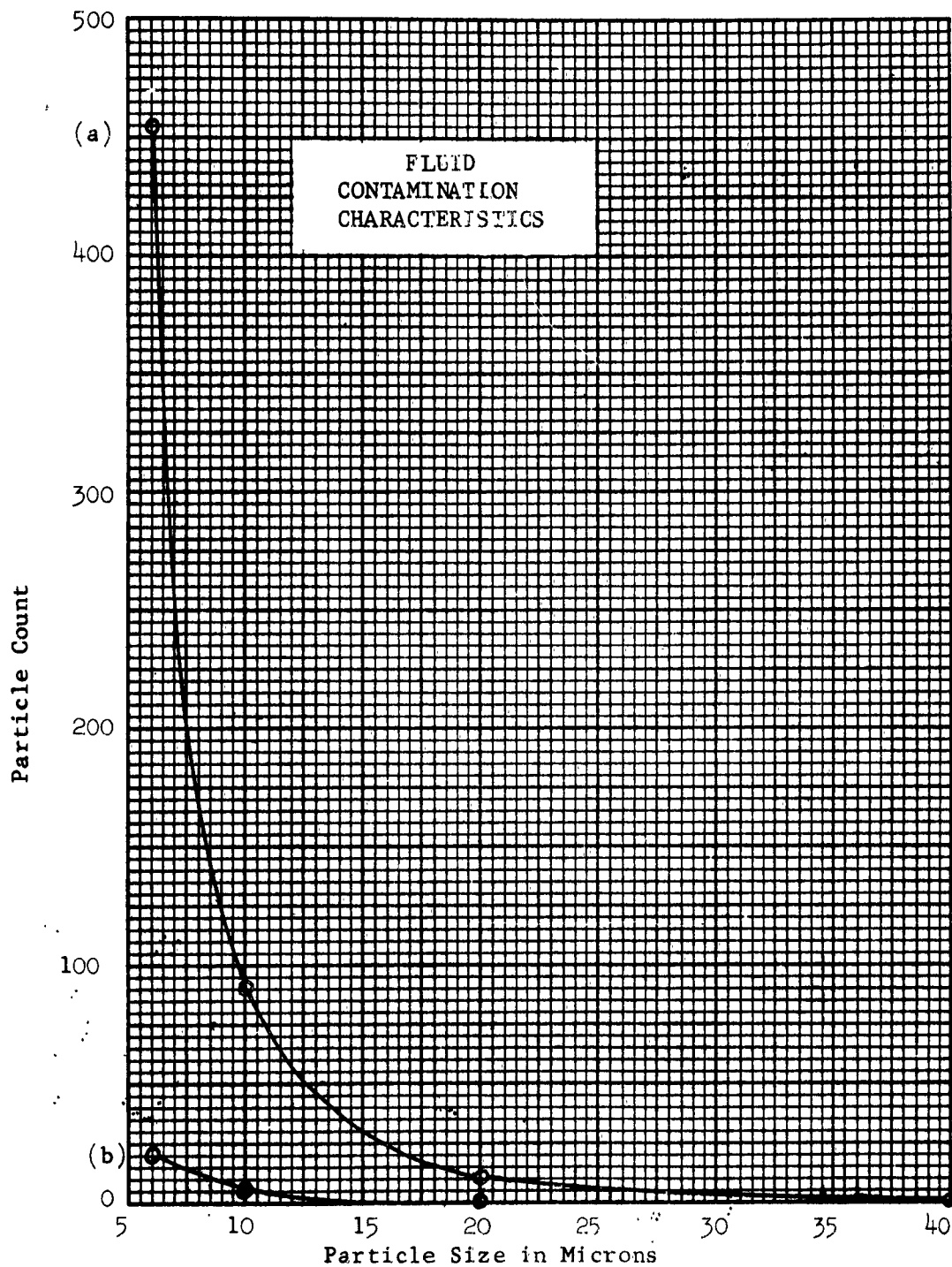
Origin of Sample:
  a. "as received" condition
  b. distilled

Fig. 7-5. Particle Size Distribution for Freon T. F.

RESULTS

The OSU Cleaning Fluid Stand fulfills the purpose for which it was
intended. It is now possible to have available large amounts of "clean"
fluid, necessary to proceed with hydraulic component cleaning tests.
From observing the result of the contaminant distribution tests, an
estimate can be made of the contaminant level that can be expected in
the Freon T. F. and trichloroethylene obtained from the manufacturers,
as well as the capability of further purifying these solvents utilizing
the Cleaning Fluid Stand or distillation apparatus.

A comparison of the particle counts of the trichloroethylene "as
received" and samples of the solvent dispensed from the Cleaning Fluid
Stand without Millipore filtration, shows there is little notable dif-
ference in these values. Yet, when one Millipore filter is included
in the stand system, a conspicuous reduction in the particle count was
observed. Then if reagent solvent cleanliness is desired, the Millipore
filtration must be used. Further cleaning of the solvent is accom-
plished by triple filtrating the trichloroethylene in a separate Milli-
pore unit; however, when large amount of the clean solvent is necessary,
this method is impractical. The installation of in-line Millipore ap-
paratus to tri-filter the solvent in the stand minimizes the handling,
and facilitates the operation of attaining a very clean solvent. The
inclusion of the Hilco filter with the Millipore filter in the Cleaning
Fluid Stand system serves to prolong the life of the Millipore pads.

The values of contaminant in the distilled trichloroethylene approx-
imates those found in samples from the stand using uni-millipore filtra-
tion. These values were also very similar to OCAMA's contaminant measure-
ments of distilled trichloroethylene. Apparently, the capabilities of
these two methods of purification are equivalent; however, the samples
of solvents were relatively clean initially.

An alternate test was performed on heavily contaminated trichloro-
ethylene to test its recoverability by distillation; however many parti-
cles were entrained in the trichloroethylene during this distillation.
It is suspected that the violent action of the trichloroethylene in the
distiller promotes the "carrying-over" of particles to the distilled
trichloroethylene.

The Freon T. F. was recovered by distillation. No mechanical fil-
tration of this solvent was attempted due to its volatility at opera-
ting temperatures, and the ease with which it can be distilled. A very
important factor in obtaining "clean" solvents is the meticulous hand-
ling of the solvents; therefore, a minimum of handling is desirable.
The tests described in this report were conducted in an air-conditioned
laboratory. In all probability, lower values of contaminant would have
been found had the OSU "clean" room been used for the performance of
these tests. However, duplication of the atmosphere encountered during
normal handling of the solvents was stressed.

INTERIM REPORT 63-6
HYDRAULIC COMPONENT CLEANLINESS EVALUATION

Ref: Contract AF 34(601)-14090
      Order Number 63-3

Date: August 26, 1963

School of Mechanical Engineering
Oklahoma State University
Stillwater, Oklahoma

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INTRODUCTION

The OSU filter evaluation laboratory has for some time now been working closely with OCAMA on problems involving aircraft hydraulic filter elements. This investigation has primarily been focalized on finding ways of reducing and controlling contamination in hydraulic systems, particularly in relation to the system filters.

Although methods for cleaning filter elements have been fairly well established, a reliable mode of ascertaining the cleanliness of the elements is still needed. Many of the present methods used in the evaluation of filter cleanliness are misleading. Other methods may leave the filters in a more contaminated condition than originally received. Some of these methods are dirt loading, fluid pressure drop, and air pressure drop. A nondestructive test that would divulge filter element cleanliness and eliminate unwanted contaminant from being intro- duced into a hydraulic system by these re-cleaned filter elements would be highly desirable. OCAMA has proposed such a test, and it is presently being evaluated.

The cleaning evaluation test developed at OCAMA (OCNERH Project 61R-75R) is performed concurrently with ultrasonic filter cleaning. The effectiveness of the ultrasonic cleaning is measured by an analysis of the particle size and count in a fluid sample removed from the ultrasonic tanks following a cleaning cycle.

An alternate cleanliness test proposed by OCAMA, practical only when

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a small number of tests are conducted, is described in OCNERH Project 61R-75R. This report states: "At the end of the cleaning cycle, after a three-minute period of ultrasonic agitation, take a 300 ml sample of the ultrasonic cleaning fluid from the tank. This sample will be filtered through white Wattman Filter paper or equivalent. The filter paper shall remain white as determined by visual inspection."

Although the above tests appear adequate, they are either time consuming or qualitative in nature. In view of the quantitative requirements needed to evaluate the OCAMA proposed test, OSU purchased a HIAC automatic particle counter for particulate examination of cleaning solvents. This equipment facilitates and accelerates the operation of obtaining quantitative data on filter cleanliness.

In order to initiate this investigation, OCAMA and OSU mutually selected two solvents as the ultrasonic medium for cleaning and testing of filter elements. The two solvents selected were trichloroethylene (O-T-643), and Freon T. F. (trichlorotrifluoroethane), a trade name of a fluorocarbon solvent developed by DuPont.

These two chemicals were chosen because of their reputation as industrial cleaning solvents and their ease of handling. Both solvents are rated as being fairly safe and as requiring fewer precautions than do some of the other effective agents in cleaning filter elements. Freon T. F. is currently being used in industry where high precision cleaning is required.

In order that the data obtained at OSU be compatible with OCAMA's efforts in filter cleaning, the cleaning and evaluation of the filter elements were made in an environment similar to that found in field operations.

The cleaning and evaluation work performed at OSU consisted of cleaning available F-105 service-contaminated aircraft filter elements. These woven wire elements were received for the F-105 program presented in Interim Report 62-2. Tests on the cleanability of these filter elements using trichloroethylene and Freon T. F. in combination with a Bendix ultrasonic cleaner (Model SEC-1016-S-1) are included in this report.

Information on the solid particle content of the cleaning solvents used in this study is presented in Interim Report 63-5. The use of these solvents in their clean state requires a standardization of the test procedures for all equipment used. Standardization of these test procedures were formalized by using the HIAC particle counter. Also, careful consideration was given to the sampling procedure to insure that a representative sample was obtained for analysis. Necessary tests were performed on sample transfer characteristics and counter operating procedures to insure that operator confidence was instilled and truly representative data was obtained from the counter. Only after these preliminary steps were completed could the study on filter cleanliness evaluation be confidently pursued.

AUTOMATIC PARTICLE COUNTER

The success of this filter cleanliness evaluation study was
dependent upon the acquisition of necessary equipment to enable OSU per-
sonnel to accurately and rapidly count the particles existing in a fluid
sample. An automatic particle counter was deemed necessary in order to
obtain reliable results in the high contamination levels expected. Other
methods of counting foreign particles have been shown to be slow, tedious,
and of questionable accuracy with high particle counts. Therefore, the
only decision to be made concerning particle counting was in deciding
which automatic particle counter to purchase. A HIAC Automatic Particle
Counter was selected to implement this study.

Operating Principles and Calibration of the HIAC

The HIAC Automatic Particle Counter was chosen for a number of reasons.
First, the operation of the HIAC is extremely simple and easily mastered.
Second, the HIAC is very well suited to the techniques of laboratory analy-
sis. Third, this counter is considerably faster than optical methods.
Fourth, the counter is completely subjective; it is free from operator
bias. And fifth, the HIAC performs particle discrimination by use of a
photoelectric cell, thus eliminating the need for mixing the sample with
other fluid having questionable contaminant levels and interactive effects.

During operation of the HIAC Particle Counter, the fluid specimen is
forced through a sampling tube into a fluid passage by pressurizing the

fluid in a sample bottle. This fluid passage is designed so that any
foreign particles in the fluid must pass single file by a counting window.
A parallel light beam is focused to penetrate this window, the fluid, and
finally impinges on a phototube inside the unit. The resulting phototube
output (Ep) is constant unless a particle passes the window, and interrupts
a portion of the light beam. Any interruption causes a change in the out-
put signal (Ep) by an amount (Va) proportional to the size of the particle.
Figure 8-1 shows this theoretical change in phototube output plotted
against time. The sloping portions of the curve represent change in out-
put as the particle enters and leaves the passageway.
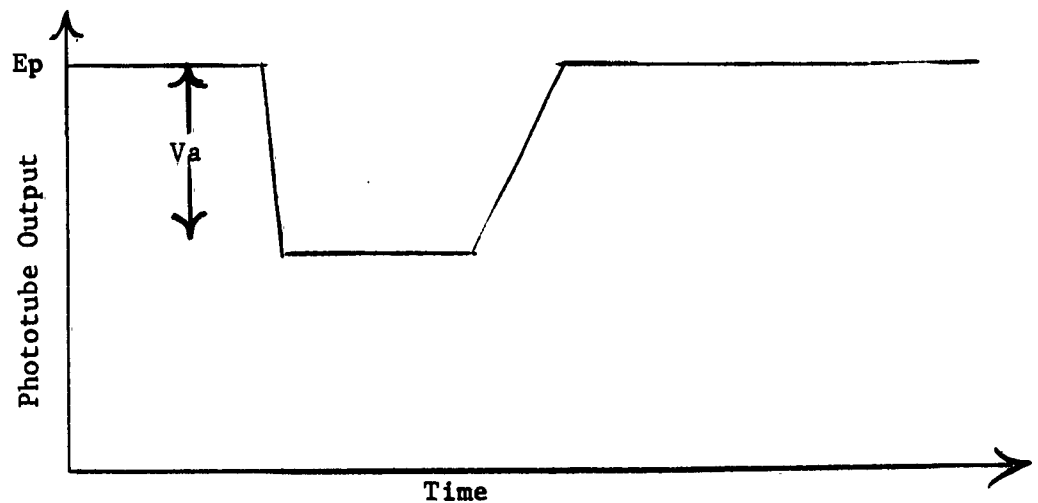

Figure 8-1

The output signal (Va) passes to the sensitivity adjustments of each
counter, where it either passes or is rejected, depending upon whether or
not its amplitude exceeds the value for which the adjustment has been set.
The signals passing through the adjustments are amplified to operate a trig-
ger, which provides the proper pulse to operate an electronic counter.

The HIAC has four separate electronic counters that can be used to enumerate particle counts in four different size ranges. After passing through the counter, the sample is collected in a graduated cylinder so that the results can be expressed as the number of particles per given volume.

The preliminary step in using the HIAC Particle Counter is the calibration of the instrument. The HIAC is calibrated by a special built-in transparent calibration disc which has photographic slides of standard size particles placed around its periphery. Different size particles can be selected to register on each of the four digital indicators by the use of this calibration disc and the separate sensitivity controls for adjustment of each indicator.

Each counter is calibrated by passing a selected particle in front of an auxiliary window while adjusting the sensitivity control knob for the counter. By adjustment of the sensitivity knob, the circuit can be set to trigger the counter when a particle of the same area or larger than the one on the calibration disc passes by the counting window. Setting these counter circuits at different sensitivities allows the unit to display counts for a wide range of particle sizes.

Test Procedure Utilizing the HIAC Counter

For this test program, the HIAC Particle Counter was calibrated for ranges of 6, 10, 20, and 40 microns. It was felt that the instrument could not be accurately calibrated and retained in calibration below 6 microns because of errors due to calibration shifts, noise level, and the extreme sensitivity of the potentiometer in small particle size ranges.

At the start of the evaluation program, the HIAC was calibrated after being allowed to warm-up approximately four hours. This calibration setting was not adjusted again during the series of tests; however, it was checked each morning after warm-up and periodically throughout the day. No significant calibration shift could be detected in a day's run.

The laboratory method (sample bottle method) of fluid analysis was used in these tests. Samples of fluid were collected in clean test bottles and connected directly to the microcell assembly. Filtered air pressure was applied to the top of the fluid sample to force the fluid through the microcell assembly for counting and sizing of the contaminant.

The operating flow rate was kept as nearly constant as possible at 60 drops/min. This flow rate was controlled by varying the back pressure on the sample bottle, and by a pinch clamp on a tube downstream from the microcell. A stop watch was used to check the flow rate.

A magnetic stirring rod was used in the sample bottles to maintain a uniform distribution of particles in each bottle. The stirring rod was propelled by a rotating magnet positioned beneath the sample bottle.

During the early tests with trichloroethylene and Freon T. F., major difficulty was experienced with air bubbles. Since the HIAC displays a count for anything that interrupts the light source, the bubbles were counted and introduced considerable error.

The bubbles were usually noticed when the sample was warm and when the HIAC was hot. Therefore, it was proposed that the solvents were vaporizing before they reached the counting window, due to the heat absorbed from the hot microcell.

This problem was solved by the design and fabrication of a cooling head, (Figure 8-2), to cool the microcell and the fluid. The cooling head
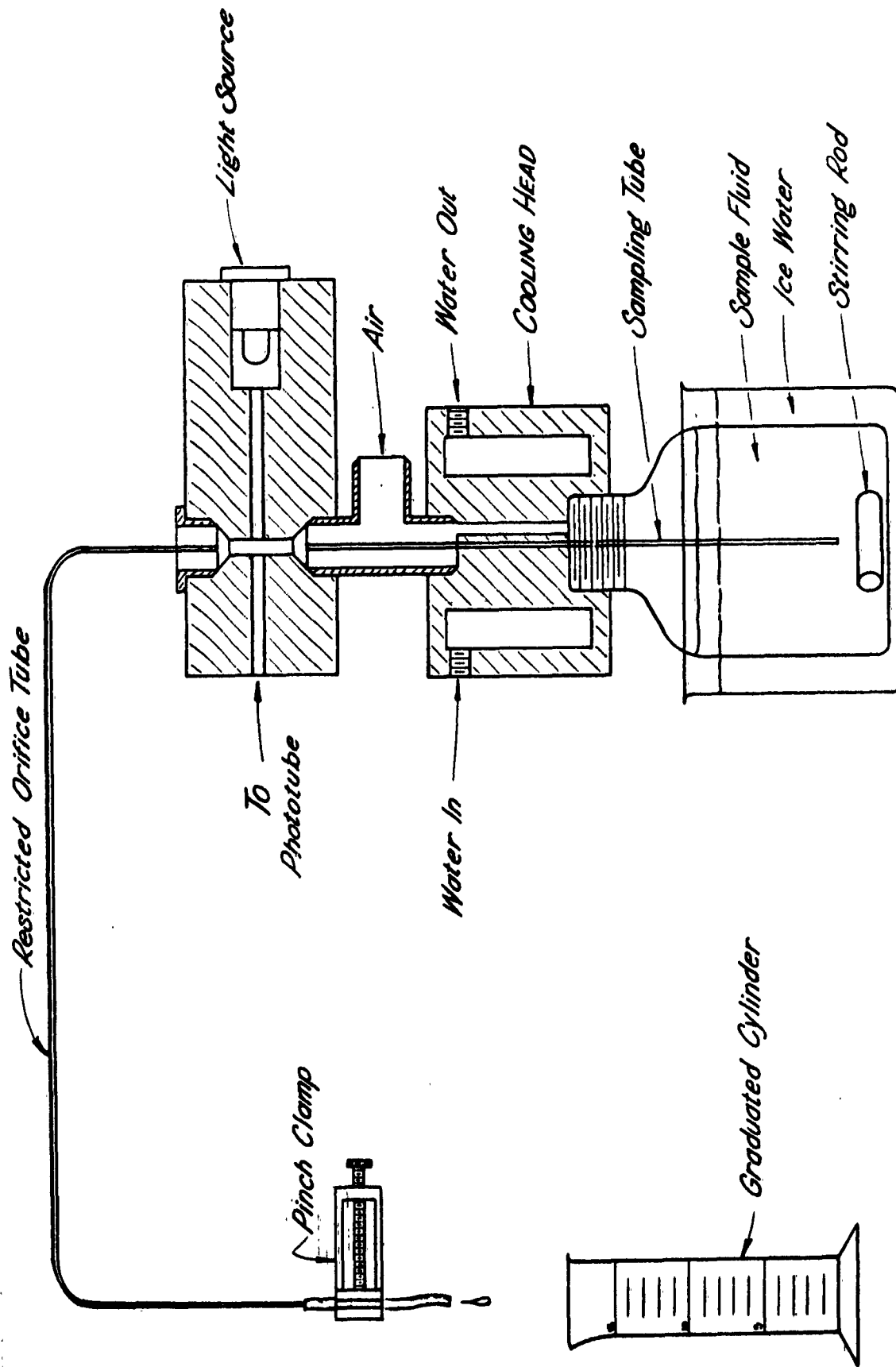
Figure 8-2   Cooling Head for HIAC Sampling Assembly

was designed to fit between the microcell and the sample bottle. Tap water, circulated first through a copper coil in an ice bath and then through the cooling head, served as the coolant. As an additional safeguard against bubbles, the samples were allowed to cool in a freezer for at least one-half hour before testing. While the contaminant in the samples were being counted, the sample bottles were placed in a beaker filled with ice in order to maintain a uniform fluid temperature.

Evaluation of Results

The particle counts were recorded for 5 milliliter samples. This size sample was chosen because of the time required to count each sample and the large number of samples required for the test program.

Even with these low-volume samples, the counts observed on a particular sample were usually within 10% of the average count. The counts from different samples collected from a particular source, such as the clean fluid stand, were approximately the same, even though they were taken at various time intervals.

Some difficulties were encountered with the HIAC; occasional failure of the light source and bubbles in the sample fluid were the major ones. These difficulties were solved and the data eventually obtained is believed to be truly representative of the sample fluid and completely reliable. The results obtained would indicate that the HIAC is an accurate instrument for counting particles of either high or low concentrations, if mechanical difficulties are removed and the counter is manipulated by an experienced operator.

CLEANING PROCEDURES AND RESULTS

Three methods are currently in use to evaluate component cleaning techniques and component cleanliness. These methods are:

(1) Static Fluid Sampling - A fluid-holding cavity in the component is filled with a fluid compatible with the system to which the component belongs. The component is then vibrated, and a contaminant analysis is performed on the fluid in the cavity.

(2) Flow Through Sampling - A flow through cavity in the component is filled with a system-compatible fluid, sealed, and vibrated. Fluid is then passed through the component and a contaminant analysis performed on the efflux.

(3) Rinse Fluid Sampling - The component is placed in a container of system-compatible fluid and vibrated. A contaminant analysis is then performed on the rinse fluid.

Of the three methods outlined above, the rinse fluid sampling method was chosen to evaluate the effectiveness of trichloroethylene and Freon T. F. as ultrasonic cleaning fluids. This method was chosen because of its adaptability to the checking of a greater variety of component configurations. Also, ultrasonic energy could be applied to the component more directly using the rinse fluid method than in the other methods.

Hydraulic filter elements were chosen as subjects for evaluating the

respective merits of the solvents considered in the test program. This selection was made because of the availability of suitable elements and their complexity with regard to cleanability. The filter elements tested (APM part No. AC-730E-8) were a part of the group evaluated and reported on in Interim Report 62-2. These filters were both service contaminated (up to 200 hours), and artificially contaminated by dirt loading with AC Fine Test Dirt.

Prior to cleaning the elements in the respective solvents, each element was placed in a beaker containing orthodichlorobenzene and subjected to three minutes of ultrasonic cleaning. This procedure was followed to remove oil and the more accessible contamination. The filters were then rinsed with hot water and isopropyl alcohol to remove the orthodichlorobenzene.

Sampling Procedures

A discussion of the sampling techniques used in this study must precede any consideration of actual test results. This is necessary because the accuracy of any determination of fluid contamination is dependent upon the validity of the fluid sample being analyzed. If the sample is not truly representative of the actual contamination level, no consistent or independently reproducible data can be obtained.

After preliminary testing, the following procedures were adopted as yielding representative fluid samples.

(1) All glassware used was washed in a self-rinsing detergent and rinsed with hot tap water.

(2) The glassware was then rinsed with triple-filtered isopropyl alcohol and petroleum ether.

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(3) Following steps (1) and (2), the glassware was covered with "Saran Wrap" to prevent the entry of airborne contaminant.

(4) Prior to each cleaning cycle, a teflon or glass-coated, magnetic stirring bar was placed in the bottom of the cleaning vessel (a 500 ml graduated cylinder).

(5) The graduate was then rinsed and filled with 200 ml of the solvent to be used in the particular cleaning test.

(6) The filter element to be cleaned was then suspended in the solvent and the respective cleaning cycle carried out.

(7) Following cleaning, the graduate was removed from the ultrasonic tank and placed on a magnetic stirrer. This was done in order to distribute uniformly the contaminant removed during cleaning.

(8) A sample of the fluid was then taken in a 125 ml sample bottle which had been cleaned in the prescribed manner and which also contained a stirring bar. Two methods of sampling were used and both were found to be satisfactory when used properly.

 (a) Direct Pouring - After stirring the rinse fluid for a minute, a sample was poured from the graduate into a sample bottle.

 (b) Pipette Transfer - After stirring the rinse fluid, a sample was drawn into a 100 ml volumetric pipette and transferred to a sample bottle. Difficulty in cleaning the pipettes limits this technique; however, if care is taken the method gives a valid sample.

(9) One additional safeguard was employed to limit the addition of foreign contamination to the test system. The same graduate

and sample bottle were used for every cleaning cycle on a given element.

An attempt was made to keep the procedures outlined above as practical as possible, so that they could be duplicated in a shop or other non-clean-room environment.

Filter Cleaning and Evaluation with Trichloroethylene

After establishing the sampling techniques to be used, ultrasonic cleaning tests were inaugurated on seven filter elements using trichloro-ethylene as the solvent. Four of the elements were subjected to 10 ten-minute cleaning cycles in a 500 ml graduated cylinder. After each cycle, the rinse fluid was sampled in the prescribed manner. The graduate was then cleaned and refilled for the next test. The element was also surface-rinsed with triple-filtered solvent before the next test.

The results of the tests on these four elements are shown in Figure 8-3 as a graph of rinse fluid contamination versus cleaning time. Two curves are shown which represent the average contamination level and the limiting or maximum contamination level versus cleaning time. These curves, while based on results from only four filters, give an insight into the cleaning process. From the curve for the average contamination level it can be seen that a stabilized region is reached after approximately 30 minutes of cleaning time. The particles in the rinse fluid samples taken after the third cleaning resulted primarily from transferring the solvent from the clean fluid stand to the graduate and finally to the sample bottle. While some particles were certainly removed from the elements after three cleanings, the results indicated that for practical purposes the filter had been cleaned to a minimum contaminant removal level in three cleanings using trichloroethylene as the solvent.

TABLE 8-1

Dirt Capacity Tests for Filter Elements Cleaned with Trichloroethylene

Ser. No.	Initial	After Cleaning	Change	Cleaning Method
2225	-	1.59	-	10x10 in Grad.
2238	1.65	1.56	-0.09	10x10 in Grad.
2613	0.28	1.72	1.44	10x10 in Grad.
4438	1.42	1.49	0.07	10x10 in Grad.
4681	1.84	1.63	-0.21	10x3 in Grad.
3966	1.58	1.67	0.09	9x10 in apparatus of Fig. 3, 10x10 in Grad.
5840	1.82	1.79	0.03	9x3 in apparatus of Fig. 3, 1x10 in Grad.

A comparison of the contaminant capacities as reported in Interim Report 62-2 and the capacities of the elements after cleaning is shown in Table 8-1. The results for the four filters discussed above show that the capacities were either increased or essentially unchanged as a result of the cleaning process.

In order to determine the influence of cleaning time on the effectiveness of the cleaning process, an element was subjected to 10 three-minute cleanings. The results, Figure 8-4, show that the stabilized region is reached shortly after the third cleaning as was the case using ten minute cleaning cycles. A comparison of the contaminant capacity after cleaning with the previous results indicate that the element was not cleaned to its maximum capacity with this method. However, this finding does not necessarily cast doubt on the particular cleaning technique since the filter did hold more than its rated capacity.

In order to reduce the handling of the test elements, the apparatus shown in Figure 8-5 was constructed. Two filters were cleaned in the apparatus, one with 9 ten-minute cycles and the other with 9 three-minute cycles. Following each cleaning cycle the element was flushed with triple filtered fluid from the clean fluid stand. After subjecting each element to nine cleanings, each was cleaned ten minutes in a graduate. Particle counts from these cleanings are shown in Table 8-2. In comparing these results with the average curve from Figure 8-3, it can be seen that no appreciable change in the contamination removal level has been effected using this cleaning technique. Investigation of the contamination capacity tests also shows that nothing was lost using this apparatus and procedure. However, a reduction in fluid handling was gained. These contaminant capacity curves are presented in Figures 8-6 and 8-7.
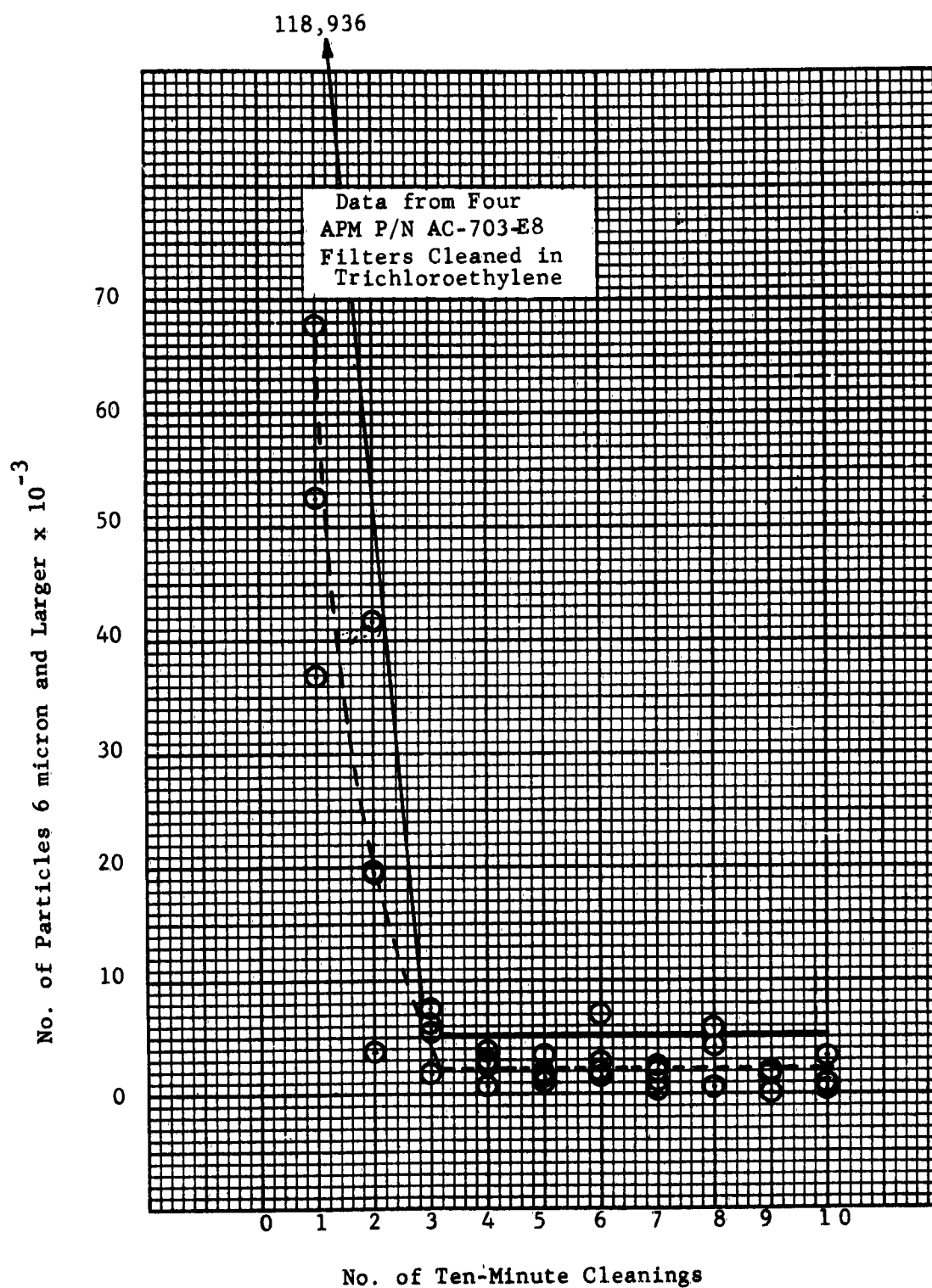
Figure 8-3 Comparative Contaminant Removal Levels
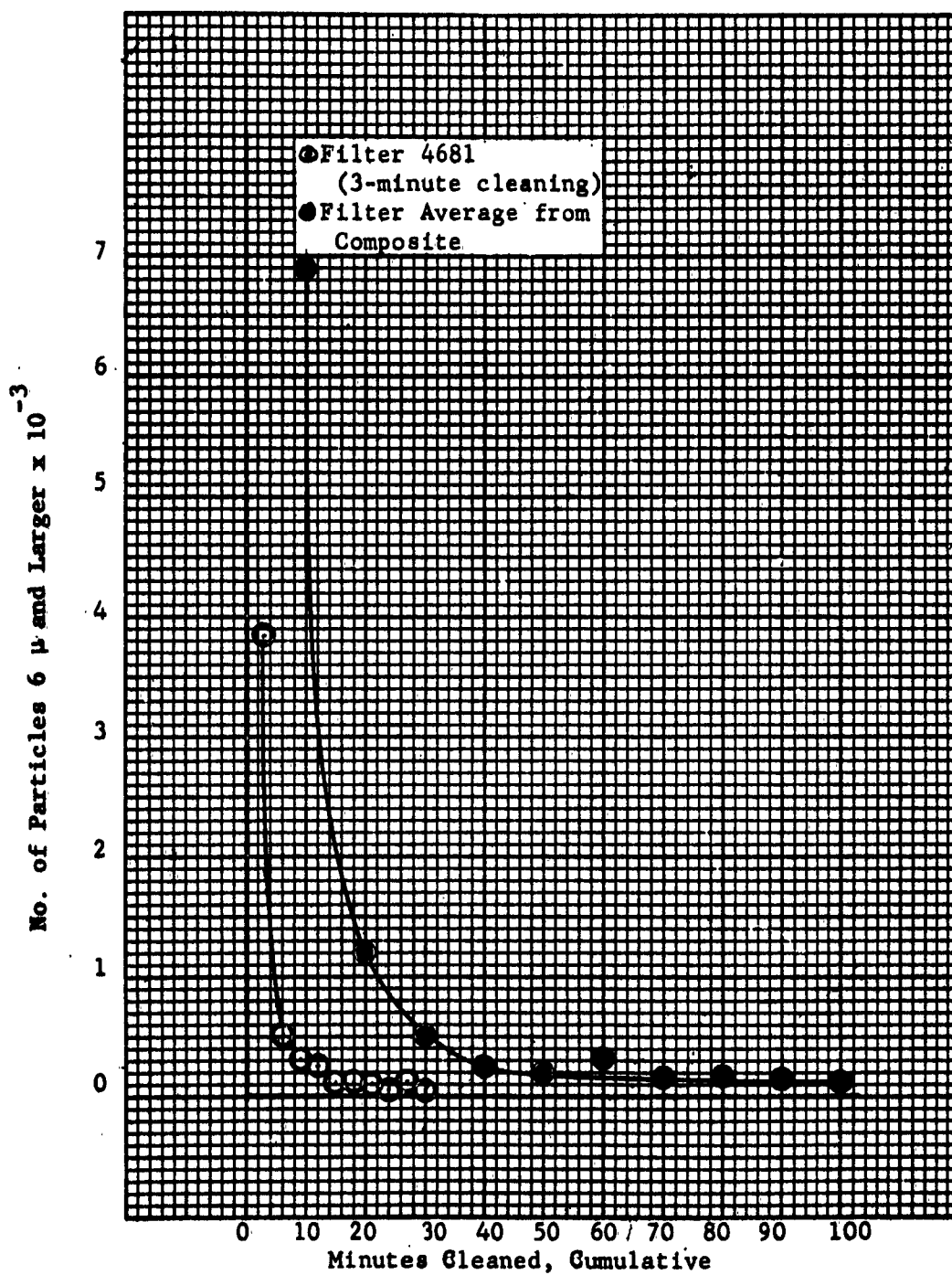
Figure 8-4

Variable Cleaning Time Comparison
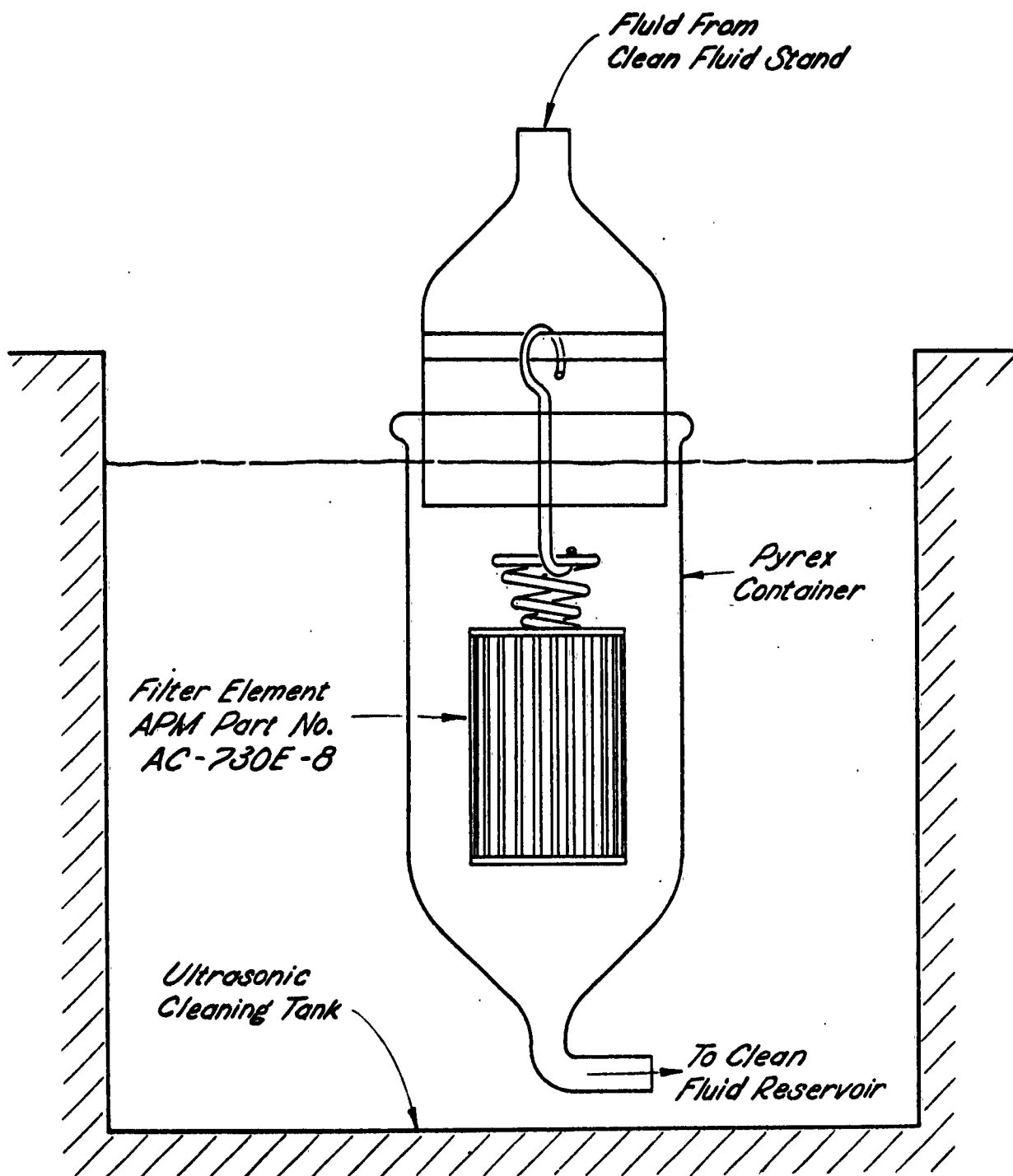
Figure 8-5   In-Line Cleaning Apparatus

TABLE 8-2

FILTER EVALUATION LABORATORY
OKLAHOMA STATE UNIVERSITY
FLUID CONTAMINANT ANALYSIS

ORIGIN OF SAMPLE __Cleaning #10 after 9 in-line cleanings__

__Filter 5840 3 min x 9 10 min x 1.__

TEST CONDUCTED BY __B. R.__ **DATE** __7-26-63__ **TYPE OF FLUID** __tri-chlo__

PARTICLE COUNT ANALYSIS

METHOD OF SAMPLING __bottle__ **PHOTO TUBE CURRENT** __50 microamp__

TEST FLOW RATE __60 drops/min__ **TEST VOLUME** __5 ml.__

PARTICLE DIAMETER (μ)	PARTICLES ABOVE SPECIFIED DIAMETER			
	TEST 1	TEST 2	TEST 3	AVERAGE
6	957	852		904
10	177	148		
20	15	14		
40	0	0		

REMARKS _____

GRAVIMETRIC ANALYSIS

WEIGHT OF FILTER PAD AND CONTAMINANT _____

WEIGHT OF DRY FILTER PAD _____

WEIGHT OF CONTAMINANT _____

TARE WEIGHT OF TEST FLUID _____

CORRECTED CONTAMINANT WEIGHT _____

VOLUME OF FLUID TESTED _____

GRAVIMETRIC ANALYSIS RESULTS (mg/liter) _____

REMARKS _____

TABLE 8-2
Continued
FILTER EVALUATION LABORATORY
OKLAHOMA STATE UNIVERSITY
FLUID CONTAMINANT ANALYSIS

ORIGIN OF SAMPLE __Cleaning #10 after 9 in-line cleanings in__
____glass Filter 3966,____

TEST CONDUCTED BY___B. R.____DATE__7-25-63___TYPE OF FLUID__tri-chlo____

PARTICLE COUNT ANALYSIS

METHOD OF SAMPLING___bottle____PHOTO TUBE CURRENT___50 microamp____
TEST FLOW RATE__60 drop/min.____TEST VOLUME__5 ml.____

PARTICLE DIAMETER (μ)	PARTICLES ABOVE SPECIFIED DIAMETER			
	TEST 1	TEST 2	TEST 3	AVERAGE
6	1342	1556		1449
10	336	303		
20	50	52		
40	9	8		

REMARKS____

GRAVIMETRIC ANALYSIS

WEIGHT OF FILTER PAD AND CONTAMINANT____

WEIGHT OF DRY FILTER PAD ____

WEIGHT OF CONTAMINANT____

TARE WEIGHT OF TEST FLUID____

CORRECTED CONTAMINANT WEIGHT____

VOLUME OF FLUID TESTED ____

GRAVIMETRIC ANALYSIS RESULTS (mg/liter)____

REMARKS ____

APM P/N AC-703-E8
Filter Serial No. 5840
Date: 7-5-63

Figure 8-6 Contaminant Capacity Curve

8-23
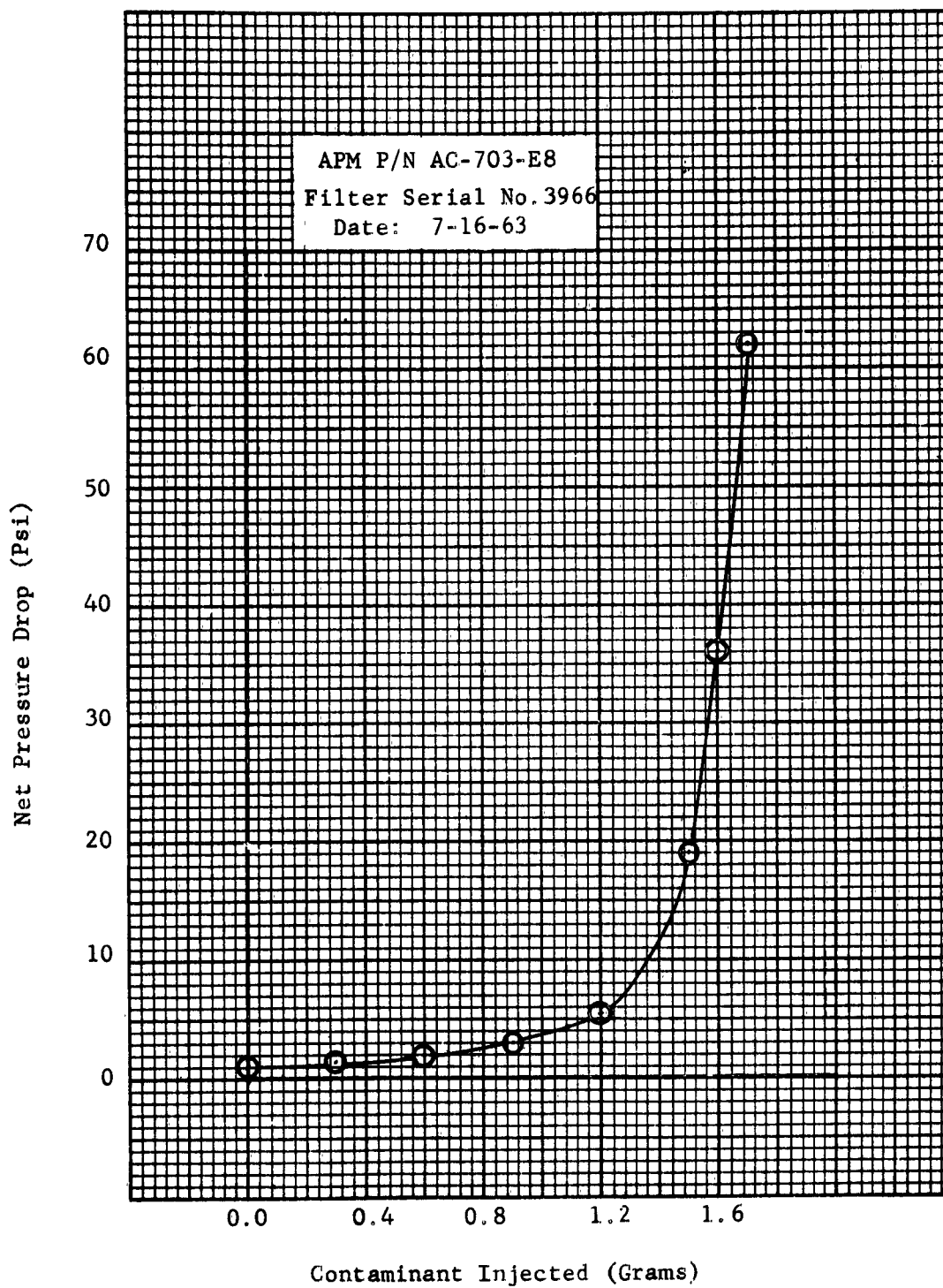
Figure 8-7 Contaminant Capacity Curve

FILTER CLEANING AND EVALUATION WITH FREON T.F.

Ultrasonic cleaning tests were run on six elements using Freon T. F., employing the procedures outlined previously for trichloroethylene. Three of these elements were subjected to 10 ten-minute cleanings and a particle count analysis was made after each cleaning cycle.

The results of this test are shown in Figure 8-8 as a plot of particle count versus cumulative cleaning time. From the data recorded during the cleaning of these three elements, two curves were plotted, one of which represents the average particle count versus cumulative cleaning time, and the other the maximum particle count versus cumulative cleaning time. Examination of these two curves indicates a stabilized region occurred after 5 cleanings or 50 minutes of cleaning time. Again as in the case of trichloroethylene, fluxuations occur in the stabilized region due to blank analysis or system tare. A discussion of the distillation and particle analysis of the cleaning fluid used in these tests is presented in Interim Report 63-5 and Appendix A of this report.

The remaining three elements were cleaned ten times in Freon T. F. for ten-minute intervals. The graduate, used for immersion of the element in the Freon T. F., the stirring rod, and the filter element were flushed with filtered trichloroethylene after each cleaning cycle. A particle analysis was made after the tenth cleaning to determine if the element had responded to cleaning and the particle count had reached the stabilized region. In each case, the particle count had reached this region.

Dirt capacity tests were then performed on all six elements and the

results compared with the data available from Interim Report 62-2. The
results of these tests are tabulated in Table 8-3. After cleaning, the
six elements the dirt capacity of three of the elements had increased
while the dirt capacity of the remaining three elements showed a slight
decrease. Although the dirt capacity did decrease for three of these
elements, their dirt capacity did compare favorably with the average of
1.59 gms of dirt capacity reported for five new filter elements in
Interim Report 63-2.

Data from Three
APM P/N AC-703-E8
Filters Cleaned in
Trichloroethylene

No. of Particles 6 micron and Larger x 10^{-3}

70

60

50

40

30

20

10

0

0   1   2   3   4   5   6   7   8   9   10

No. of Ten-Minute Cleanings
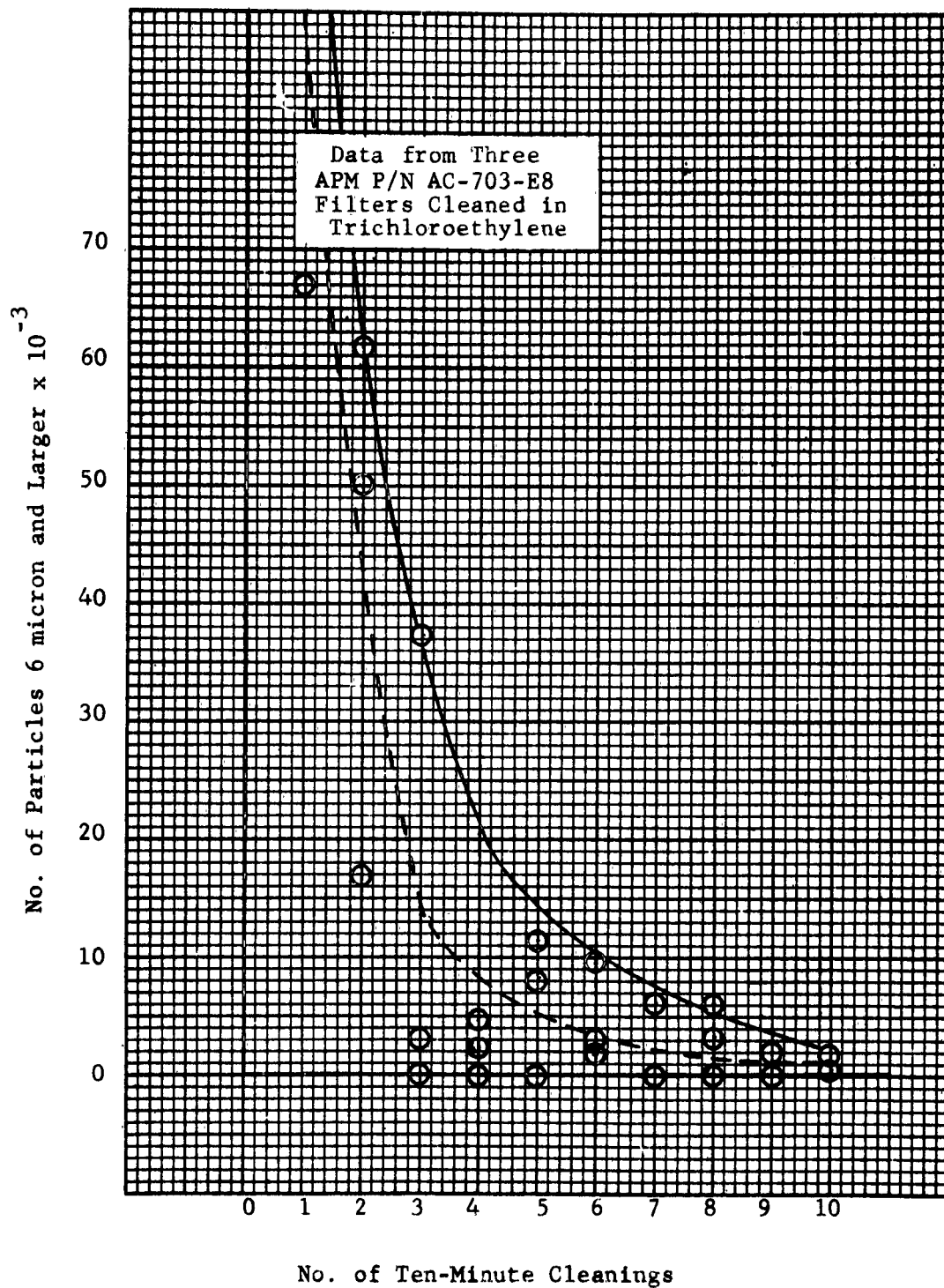
Figure 8-8 Comparative Contaminant Removal Levels

TABLE 8-3

Dirt Capacity Tests for Filter Elements Cleaned With Freon T. F.

Ser. No.	Initial	After Cleaning	Change	Cleaning Method
5914	1.82	1.68	-0.14	10 x 10 in Grad.
4778	1.37	1.38	0.01	10 x 10 in Grad.
5999	1.59	1.70	0.11	10 x 10 in Grad.
5727	1.58	1.52	-0.06	10 x 10 in Grad.
5380	1.48	1.50	0.02	10 x 10 in Grad.
1086	1.70	1.64	-0.06	10 x 10 in Grad.

COMPARISON OF TRICHLOROETHYLENE AND

FREON T. F. SOLVENTS

The results of the previous section indicate that either Trichloro-ethylene or "Freon" TF is a satisfactory cleaning agent in which hydraulic parts can be cleaned with the use of ultrasonic equipment. However, it was desired to further investigate the comparative effectiveness of the two solvents. Such a comparison can be made if the testing procedures for both solvents are kept as similar as possible.

Procedure

In order to make this comparison, the following procedure was devised. Hydraulic filters that had been cleaned ten times in trichloroethylene, using the procedure outlined in this report, were then cleaned the eleventh time in trichloroethylene. After the eleventh cleaning, the number of particles removed from the filter during this final cleaning were determined utilizing the HIAC Particle Counter.

With the data collected from cleanings number ten and eleven, a comparison of the relative cleaning ability of the two solvents was made. The assumption was made that the effectiveness of the two solvents were not equivalent. Therefore, if a filter cleaned ten times in the less effective solvent was cleaned for the eleventh time in the more effective solvent, more particles would be removed than if a filter was first cleaned in the more effective solvent. The data obtained support this assumption.

The data presented below are counts of the number of six micron or

larger particles contained in five milliliter samples of the solvent used to clean the filter. These counts were obtained by the use of the HIAC Particle Counter. Figure 8-9 and Figure 8-10 are graphical representations of the six micron and larger particles tabulated in Tables 8-4 and 8-5 and are included for a visual comparison of the data.

TABLE 8-4

Filter No.	Particle Size (Microns)	No. of Particles from Cleaning 10 (Freon T.F.)	No. of Particles from Cleaning 11 (Trichloroethylene)
4693	6	517	17,991
	10	141	3,229
	20	16	490
	40	1	27
5999	6	1,195	19,522
	10	446	2,882
	20	79	150
	40	6	6
2497	6	623	14,366
	10	155	3,751
	20	17	319
	40	1	14

TABLE 8-5

Filter No.	Particle Size (Microns)	No. of Particles from Cleaning 10 (Trichloroethylene)	No. of Particles from Cleaning 11 (Freon T.F.)
2613	6	314	1,327
	10	92	177
	20	6	9
	40	1	1
5380	6	1,080	790
	10	94	191
	20	3	31
	40	0	1
5914	6	887	660
	10	133	131
	20	9	20
	40	0	0

■ Particle Count for 10th Cleaning in Freon T. F.

☐ Particle Count for 11th Cleaning in Trichloroethylene
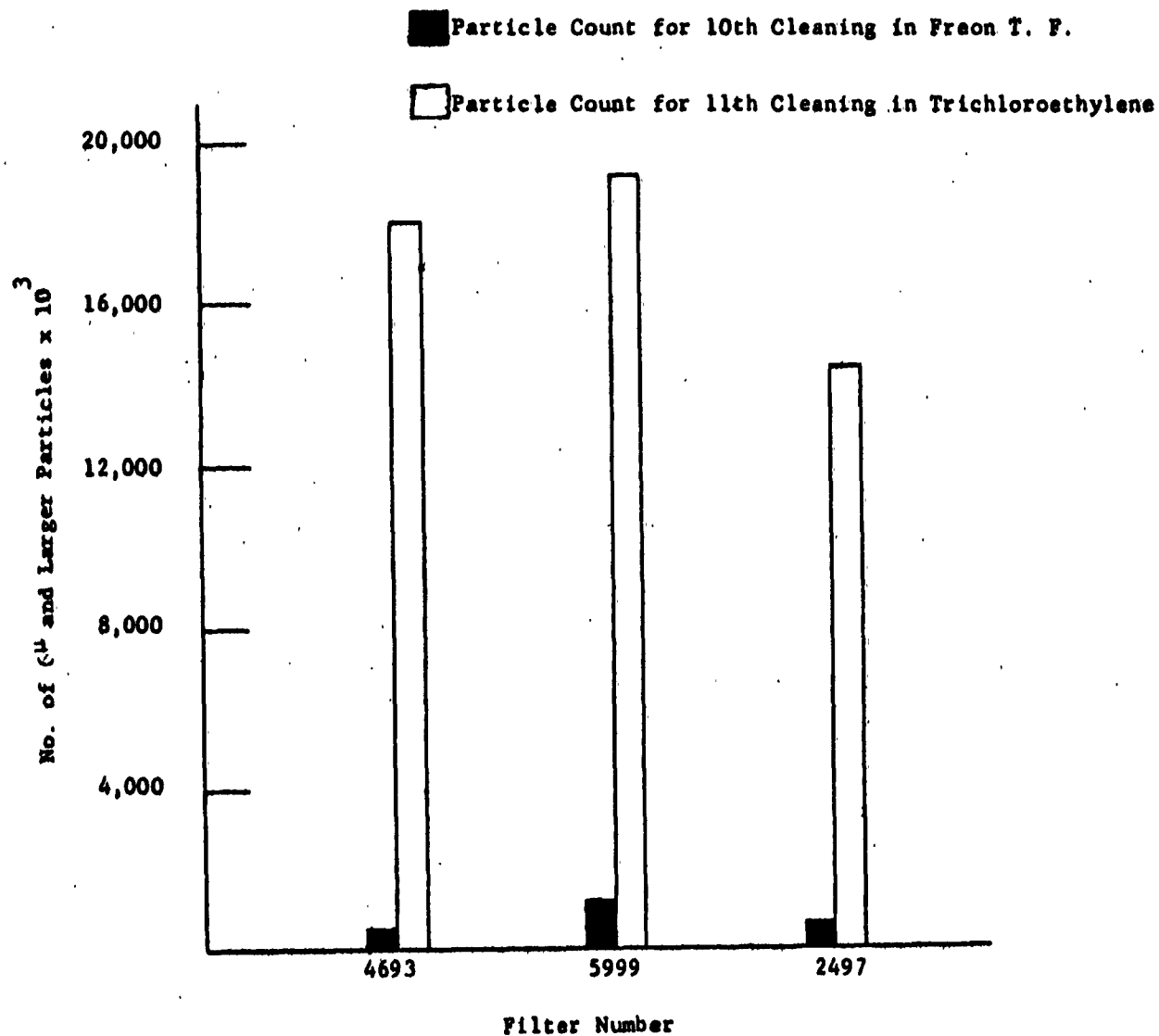
Figure 8-9 Comparative Solvent Power

8-33
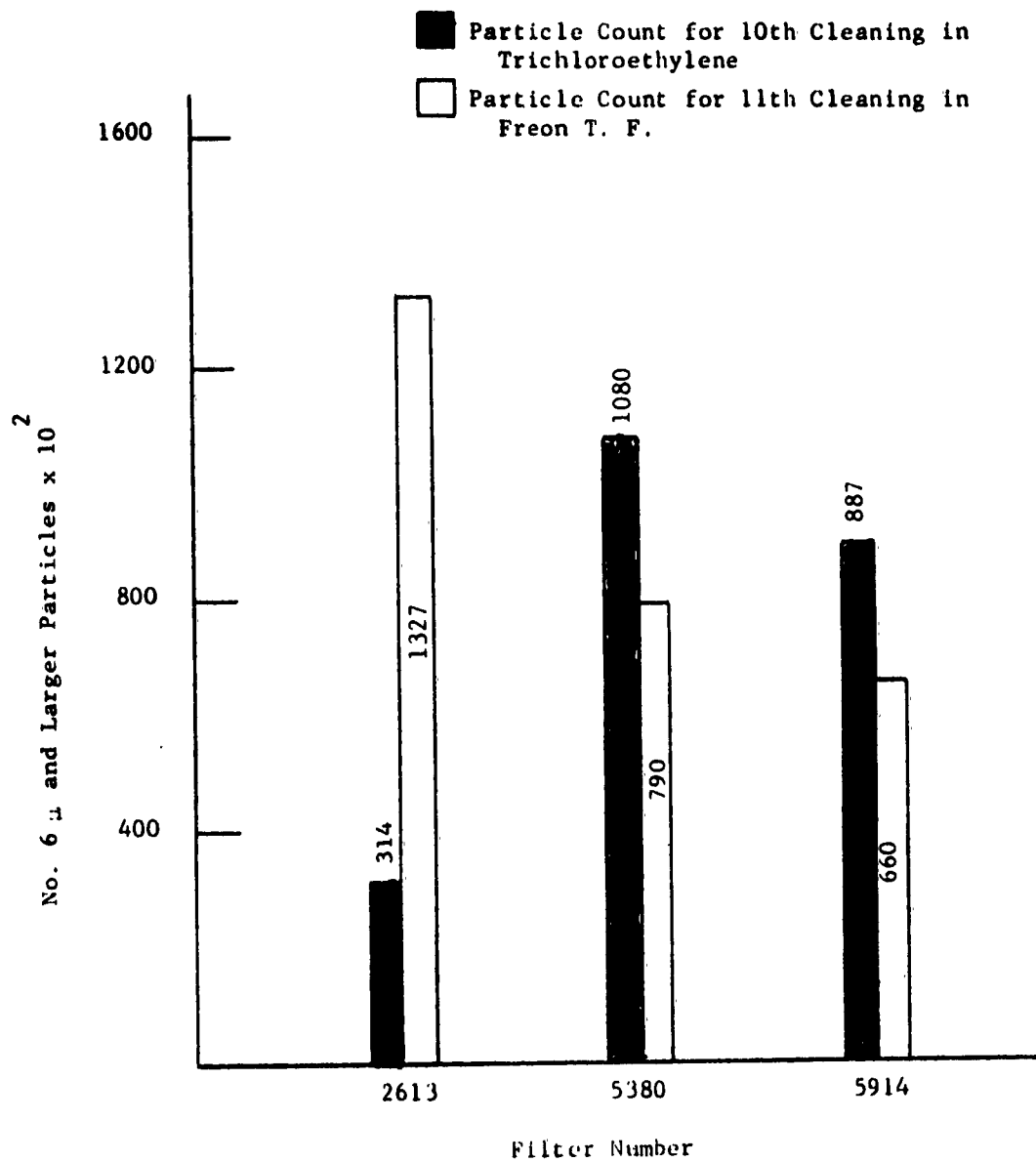
Figure 8-10 Comparative Solvent Power

Discussion

The data presented in Table 8-4 and Table 8-5 shows there evidently exists a conspicuous difference in the cleaning ability of the two solvents, when based upon the solvent particle count. The number of particles added to the cleaning agent during the tenth cleaning of the elements in Freon was between 500 -1,200 particles of six microns or larger, indicating that the filter elements were relatively clean. However, when the same filter elements were cleaned in trichloroethylene, between 14,000 - 20,000 particles of six microns or larger were added to the cleaning medium. Obviously the filter had retained a considerable number of six micron or larger particles after ten cleanings in Freon T. F.

As further evidence of trichloroethylene favorability, note the results obtained from the filter cleaning in Freon T. F. following the ten cleanings in trichloroethylene. The range of six micron or larger particles removed during the tenth cleaning in trichloroethylene was 300 - 1,100. The eleventh cleaning in Freon T. F. removed only 600 - 1,300 particles of six microns or larger, which is not significantly different from the number of the same size particles removed by the last trichloroethylene cleaning. These results indicate that Freon T. F. is no better than trichloroethylene as a cleaning solvent, and in view of the results obtained by following the Freon T. F. cleaning by a trichloroethylene cleaning, it becomes evident that the trichloroethylene is the better solvent.

Conclusion

It must be remembered that the comparative evaluation of the two solvents is based entirely upon the ability of the solvent to remove particles of contamination from a hydraulic system component. Briefly then the

trichloroethylene was able to remove a significant number of particles that the Freon would not remove, whereas the Freon would remove only a few particles that had not been removed by the trichloroethylene.

In view of these results, it can be concluded that of the two solvents, the one more effective as a cleaning agent, when used in the manner of this investigation, is trichloroethylene. That is, trichloroethylene when used in conjunction with ultrasonic cleaning equipment will remove more particles from a hydraulic component than will Freon T. F.

CONCLUSIONS AND RECOMMENDATIONS

I. Introduction

This study was initiated on the premise that the particle removal rate of a hydraulic component subjected to a cleaning process would reach a steady state value. This value is dependent upon the cleaning solvent tare and sampling techniques and is independent of the cleaning solvent used. This independence may best be explained by an example of cleaning filter elements with water. Although water cannot be considered an outstanding solvent for this application, the particle removal rate as a result of using this fluid will reach a steady state value. However, the number of cleanings necessary to reach this steady state value or stabilized region of the characteristic contaminant removal curve is a function of the cleaning power of the solvent.

It should be recognized that, while steady state particle removal rate may indicate component cleanliness, care must be taken to assure that the solvent has effectively attacked the range of contaminants within the filter component. This assurance would preclude the possibility of a component being judged clean when actually the component still posses contaminant. An example of this possibility is the failure of some solvents to remove carbon residues on filter elements.

Therefore, the particle removal ability of a solvent is one criterion for the selection of a cleaning fluid. Other criteria for selection of the fluid include toxicity, flammability, allowable air concentration (threshold limit PPM) and odor.

II. Automatic Particle Counter

The HIAC Automatic Particle Counter proved to be a quick, easy, and accurate means of determining the particulate contamination in both hydraulic oils and solvents. A review of the data presented in Appendix B indicates that the HIAC Counter normally repeats within the expected 10% of the average of all counts when reiterating the count on the same sample of solvent.

The two major problems encountered with the HIAC were the occasional failure of the light source and bubbles formed by vaporization of the test fluid in the unit's microcell. A cooling head designed and fabricated by OSU personnel prevented the vaporization of the fluid in the microcell, thus allowing particle analysis to be made. Careful attention to sample preparation and operator skill is necessary to obtain representative and consistent particle counts.

III. Filter Cleaning and Evaluation

Hydraulic filter elements were chosen for the cleanliness evaluation because of the availability of suitable elements and their complexity with regard to cleanability. The elements tested (APM Part No. AC-730E-8) were selected from a group evaluated and reported in Interim Report 62-2.

Thirteen filter elements were ultrasonically cleaned using tri-chloroethylene and Freon T. F. The cleaning procedure consisted of immersing the elements in orthodichlorobenzene (Mil-c-25107) and subjecting them to ultrasonic energy for three minutes. After drying, the elements were submerged in either trichloroethylene or Freon T. F. and were subjected to ten cleaning cycles of different time intervals. A sample of the cleaning fluid was removed after each cleaning cycle

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and analyzed on the particle counter. A plot was then made of particle count versus cumulative cleaning time and is presented in Figure 8-3 and Figure 8-4.

An examination of Figure 8-3 indicates that after three cleaning cycles using trichloroethylene the cleanability of the filters had reached a stabilized region and were considered clean. Particle count data obtained on Freon T. F. are shown graphically in Figure 8-8. The test results for Freon T. F. indicate that the stabilized region of contaminant removed does not occur until after five cleaning cycles. Therefore, based upon particle removal ability, trichloroethylene appears to be a better solvent than Freon T. F.

Dirt loading tests were run on each filter element to make sure that the filter elements were clean once the particle count reached a stabilized region. The results of these dirt loading tests are tabulated in Table 8-1 and Table 8-3. In each case the dirt capacity of the elements was essentially the same or greater than the average of the five new filter elements dirt loaded and presented in Interim Report 62-2.

IV. Comparison of Trichloroethylene and Freon T. F. Solvents

A test was devised to determine the comparative ability of trichloroethylene and Freon T. F. to remove contamination from a hydraulic system component. The components used were filter elements (APM part No. 730E-8) that had been previously evaluated and reported in Interim Report 62-2. The filters had been cleaned ten times in trichloroethylene, using the procedure outlined in the previous section, were then cleaned the eleventh time in Freon T. F. Other filters were cleaned using Freon T. F. for the first ten cleanings and trichloroethylene for the eleventh cleaning. In this manner, it was possible

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to determine if one could remove contamination that had not been affected by the other solvent.

The data in Table 8-4 show that trichloroethylene removed a significant number of particles that Freon T. F. did not affect during its cleaning cycle. On the other hand, after filters were cleaned ten times in trichloroethylene, Freon T. F. did not remove any significant amount of particles during the eleventh cleaning.

These results indicate that trichloroethylene is a much more powerful solvent, for the type of contamination on filters, than is Freon T. F. This result might be expected since DuPont Technical Bulletin FST-1 lists the Kauri-Butanol number of trichloroethylene as 130 compared to 31 for Freon T. F. This empirical system (Kauri-Butanol numbers), which serves as a general guide to relative solvent power, places Freon T. F. just above kerosene in solvent power. Results also indicate that although Freon T. F. can remove considerable contamination from a dirty filter, it does leave some substance that trichloroethylene is able to remove.

This comparison of trichloroethylene and Freon T. F. has been on a solvent basis only. The solvent power is only one of a number of physical and chemical factors involved in the selection of a cleaning agent.

V. Recommendations

Results of tests performed at OSU indicate that cleanliness of hydraulic components can be ascertained by the use of an automatic particle counter. There are two areas that require attention from the standpoint of production cleaning and testing of hydraulic components.

1. Availability of necessary cleaning and testing fluid.

2. Means of formalizing testing and cleaning procedures.

The results of this study together with results presented in Interim Report 63-5 indicate that distillation of the cleaning solvent appears to be the better approach for the removal of large amounts of contaminant from the cleaning solvent. Therefore, an ultrasonic cleaning facility with a minimum power level of 10 watts per square inch and capable of yielding its own distilled fluid is needed for successful implementation of the program outlined in this report.

Second, the HIAC Automatic Particle Counter was an invaluable tool in the formalization and establishment of the cleanliness testing and cleaning procedures used in this study. Enough emphasis cannot be placed upon the necessity of establishing reasonable but rigorous cleaning and evaluation procedures. It is felt that an automatic particle counter is invaluable in this area. Although an in-line particle counter may be expensive, its effect as a means of quality control in cleanliness evaluation should not be overlooked.

APPENDIX A

RECLAMATION OF SOLVENTS BY DISTILLATION

A program to evaluate the merits of recovering contaminated solvents by distillation appears feasible in view of the high cost of solvents now in use.

Because of a late delivery date, a laboratory type distillation apparatus was substituted for the commerical distillation unit in order that the program could proceed as planned.

Before construction, all parts of the laboratory type distillation apparatus were thoroughly washed, using the procedure outlined in this section.

The distillation unit was always allowed to run for thirty minutes before any fluid was collected in a clean flask for future cleaning and rinsing of test components or equipment.

The particle analyses for Freon T. F. and trichloroethylene are presented in Interim Report 63-5. An examination of these results show that the particle count of distilled trichloroethylene never reached the low level that was obtained with the distilled Freon T. F. A representative portion of the background data used in this study is shown in Tables 8-6 through 8-11.

This higher count is believed to be caused by the tendency of trichloroethylene to boil at an erratic rate whenever dirt is presented in moderate to heavy concentrations. It is believed that the dirt forms a temporary hot spot; this in turn causes almost instantaneous vaporization

of the fluid in a local area. When the dirt layer shifts or cracks and allows the fluid to enter this local area, a consequential violent vaporization results. This action throws a fine mist of trichloroethylene into the vapor stream and some of the smaller, less dense particles are carried over into the condenser section and then to the clean flask storage.

Freon T. F. exhibited a very uniform rate of vaporization, but does require a cold condenser temperature (around 0° C) for efficient recovery of the vapors.

It should be called that this unit was a laboratory model and will not necessarily reflect or project any problems associated with the commerical unit.

TABLE 8-6

FILTER EVALUATION LABORATORY
OKLAHOMA STATE UNIVERSITY
FLUID CONTAMINANT ANALYSIS

ORIGIN OF SAMPLE __Background from filter stand with millipore.__

TEST CONDUCTED BY __B. R.__ **DATE** __6-25-63__ **TYPE OF FLUID** __tri-chlo__

PARTICLE COUNT ANALYSIS

METHOD OF SAMPLING __bottle__ **PHOTO TUBE CURRENT** __50 microamp__

TEST FLOW RATE __60 drops/min__ **TEST VOLUME** __5 ml__

PARTICLE DIAMETER (µ)	PARTICLES ABOVE SPECIFIED DIAMETER			
	TEST 1	TEST 2	TEST 3	AVERAGE
5	152	164	130	
10	29	35	25	
20	2	0	2	
40	0	0	0	

REMARKS

GRAVIMETRIC ANALYSIS

WEIGHT OF FILTER PAD AND CONTAMINANT

WEIGHT OF DRY FILTER PAD

WEIGHT OF CONTAMINANT

TARE WEIGHT OF TEST FLUID

CORRECTED CONTAMINANT WEIGHT

VOLUME OF FLUID TESTED

GRAVIMETRIC ANALYSIS RESULTS (mg/liter)

REMARKS

TABLE 8-7

FILTER EVALUATION LABORATORY
OKLAHOMA STATE UNIVERSITY
FLUID CONTAMINANT ANALYSIS

ORIGIN OF SAMPLE ___Filter stand with millipore - background___

TEST CONDUCTED BY___B. R.___ DATE___6-23-63___ TYPE OF FLUID___tri-chlo___

PARTICLE COUNT ANALYSIS

METHOD OF SAMPLING___bottle___ PHOTO TUBE CURRENT___50 microamp___

TEST FLOW RATE___60 drops/min___ TEST VOLUME___5 ml.___

PARTICLE DIAMETER (μ)	PARTICLES ABOVE SPECIFIED DIAMETER			
	TEST I	TEST 2	TEST 3	AVERAGE
5	98	110	134	114
10	25	26	34	28
20	1	1	2	1
40	0	0	0	0

REMARKS___

GRAVIMETRIC ANALYSIS

WEIGHT OF FILTER PAD AND CONTAMINANT___

WEIGHT OF DRY FILTER PAD___

WEIGHT OF CONTAMINANT___

TARE WEIGHT OF TEST FLUID___

CORRECTED CONTAMINANT WEIGHT___

VOLUME OF FLUID TESTED___

GRAVIMETRIC ANALYSIS RESULTS (mg/liter)___

REMARKS___

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TABLE 8-8

FILTER EVALUATION LABORATORY
OKLAHOMA STATE UNIVERSITY
FLUID CONTAMINANT ANALYSIS

ORIGIN OF SAMPLE ___Background with new millipore___

TEST CONDUCTED BY___B. R.___ DATE___6-25-63___ TYPE OF FLUID___tri-chlo___

PARTICLE COUNT ANALYSIS

METHOD OF SAMPLING___bottle___ PHOTO TUBE CURRENT___50 microamp___
TEST FLOW RATE___60 drops/min___ TEST VOLUME___5 ml.___

PARTICLE DIAMETER (μ)	PARTICLES ABOVE SPECIFIED DIAMETER			
	TEST 1	TEST 2	TEST 3	AVERAGE
5	109	105		107
10	8	8		8
20	0	1		1
40	0	0		0

REMARKS___Considered third test unnecessary___

GRAVIMETRIC ANALYSIS

WEIGHT OF FILTER PAD AND CONTAMINANT_____

WEIGHT OF DRY FILTER PAD _____

WEIGHT OF CONTAMINANT_____

TARE WEIGHT OF TEST FLUID_____

CORRECTED CONTAMINANT WEIGHT_____

VOLUME OF FLUID TESTED_____

GRAVIMETRIC ANALYSIS RESULTS (mg/liter)_____

REMARKS _____

TABLE 8-9

FILTER EVALUATION LABORATORY
OKLAHOMA STATE UNIVERSITY
FLUID CONTAMINANT ANALYSIS

ORIGIN OF SAMPLE ___Distilled Freon TF___

TEST CONDUCTED BY__B. R.___ DATE__7-16-63___ TYPE OF FLUID__Freon TF___

PARTICLE COUNT ANALYSIS

METHOD OF SAMPLING__bottle___ PHOTO TUBE CURRENT__50 microamp___

TEST FLOW RATE__60 drops/min___ TEST VOLUME__5 ml___

PARTICLE DIAMETER (µ)	PARTICLES ABOVE SPECIFIED DIAMETER			
	TEST 1	TEST 2	TEST 3	AVERAGE
6	102	86		94
10	13	10		12
20	2	1		2
40	0	0		0

REMARKS_____

GRAVIMETRIC ANALYSIS

WEIGHT OF FILTER PAD AND CONTAMINANT_____

WEIGHT OF DRY FILTER PAD _____

WEIGHT OF CONTAMINANT_____

TARE WEIGHT OF TEST FLUID_____

CORRECTED CONTAMINANT WEIGHT_____

VOLUME OF FLUID TESTED_____

GRAVIMETRIC ANALYSIS RESULTS (mg/liter)_____

REMARKS _____

TABLE 8-10

FILTER EVALUATION LABORATORY
OKLAHOMA STATE UNIVERSITY
FLUID CONTAMINANT ANALYSIS

ORIGIN OF SAMPLE __Distilled Freon__

TEST CONDUCTED BY __B. R.__ DATE __7-8-63__ TYPE OF FLUID __Freon TF__

PARTICLE COUNT ANALYSIS

METHOD OF SAMPLING __bottle__ PHOTO TUBE CURRENT __50 microamp__

TEST FLOW RATE __60 drops/min.__ TEST VOLUME __5 ml__

PARTICLE DIAMETER (μ)	PARTICLES ABOVE SPECIFIED DIAMETER			
	TEST I	TEST 2	TEST 3	AVERAGE
6	66	72		69
10	24	28		26
20	1	2		2
40	0	0		0

REMARKS

GRAVIMETRIC ANALYSIS

WEIGHT OF FILTER PAD AND CONTAMINANT

WEIGHT OF DRY FILTER PAD

WEIGHT OF CONTAMINANT

TARE WEIGHT OF TEST FLUID

CORRECTED CONTAMINANT WEIGHT

VOLUME OF FLUID TESTED

GRAVIMETRIC ANALYSIS RESULTS (mg/liter)

REMARKS

TABLE 8-11

FILTER EVALUATION LABORATORY
OKLAHOMA STATE UNIVERSITY
FLUID CONTAMINANT ANALYSIS

ORIGIN OF SAMPLE __Distilled Freon__

TEST CONDUCTED BY __B. R.__ DATE __7-15-63__ TYPE OF FLUID __Freon TF__

PARTICLE COUNT ANALYSIS

METHOD OF SAMPLING __bottle__ PHOTO TUBE CURRENT __50 Microamp__

TEST FLOW RATE __60 drops/min.__ TEST VOLUME __5 ml__

PARTICLE DIAMETER (μ)	PARTICLES ABOVE SPECIFIED DIAMETER			
	TEST 1	TEST 2	TEST 3	AVERAGE
6	48	26		37
10	9	9		9
20	2	5		3
40	0	0		0

REMARKS

GRAVIMETRIC ANALYSIS

WEIGHT OF FILTER PAD AND CONTAMINANT

WEIGHT OF DRY FILTER PAD

WEIGHT OF CONTAMINANT

TARE WEIGHT OF TEST FLUID

CORRECTED CONTAMINANT WEIGHT

VOLUME OF FLUID TESTED

GRAVIMETRIC ANALYSIS RESULTS (mg/liter)

REMARKS

APPENDIX B

The data and curves presented in this section are typical of the

results obtained from the cleaning tests using Freon T. F. and trichloro-

ethylene. These filters were cleaned ten times in the ultrasonic cleaner

using ten minute cleaning intervals. After each cleaning cycle, a sample

of the fluid was removed from the cleaning vessel and a particle analysis

was performed. A plot of the particle count in the cleaning solvents ver-

sus cumulative cleaning time for each element was made as compared with

the average particle count extracted from all of the elements cleaned.

The results of cleaning four filters are presented herein. Two of the

filter elements were cleaned in Freon T. F. and three in trichloroethylene.

The results of these cleanings are presented in the "Cleaning Procedures

and Results" section of this report.

It might be reasonably expected that the amount of contaminant re-

moved from a filter would be less with each successive cleaning, However,

the data from the cleaning tests does not support this supposition. Of

all the filters cleaned, there was not one for which the amount of con-

taminant removed was a continuously decreasing function. For instance,

on Filter 2613, the amount of contaminant removed in cleaning No. 8 was

greater than the amount removed during cleaning No. 4. This example is

entirely typical of all the tests.

It is thought that this fluctuation in contaminant removal for suc-

cessive cleanings, results primarily from variations in cleanliness level

of the test apparatus. It is impossible to have all sample bottles, beakers, etc. at the same cleanliness level for each cleaning interval. Therefore, it is probable that a variation, in cleanliness of test apparatus, could cause a particular cleaning interval to have a higher count than some previous cleaning interval. Another reason for these variations might be that some particles are just harder to remove and take a longer interval of cleaning before they can be separated from the element.

It should be pointed out that these fluctuations occurred after the particle count had reached a low level. At these low levels, the fluctuations were considered to be little indication of the cleanliness of the filter element.

After cleaning, the elements were loaded with A.C. Fine Test Dust until the net differential pressure across the element reached 50 psi. The amount of contaminant injected to produce this pressure is defined as the contaminant capacity of the element. The results of the Dirt Capacity tests for these elements are tabulated in Tables 8-1 and 8-3 and some of the contaminant capacity curves are presented in this appendix.

PROPERTIES AND HANDLING OF FREON T. F.

Freon T. F. is a clear, highly volatile liquid that posseses the properties of being non-toxic, non-flammable, and chemically and thermally inert.

Its high density (94.29 lb ft^3) allows it to float impurities away from an element as they are loosened by mechanical or solvent action. It is practically insoluble in water (.009% by weight) and is a very active wetting agent.

Care must be taken in the handling of Freon T. F. to keep it below its boiling point, and thus minimize losses due to vaporization. And for this reason, precautions must be taken to keep the ultrasonic fluid bath cool.

Its action as a solvent is not as pronounced as the chlorinated hydro-carbon solvents, but Freon T. F. does not attack metals, plastics or elas-tomers as do some of the more powerful solvents.

Freon T. F. has a low surface tension, thus allowing it to penetrate small crevices and exert its solvent action within a dirt film from above, as well as from below.

Due to Freon T. F.'s chemical inertness there is no shelf life or storage problems, such as is found with more active solvents.

TABLE 8-12

FILTER 1086

CLEANED IN FREON T. F.

	Particle Size	Test 1	Test 2	Test 3	Average
Cleaning No. 1	6	64,709	69,592		67,151
	10	21,168	20,999		21,089
	20	2,065	2,247		2,156
	40	99	119		109
Cleaning No. 2	6	13,971	19,600		16,785
	10	3,202	6,114		4,708
	20	243	414		326
	40	7	15		11
Cleaning No. 3	6	75	157		116
	10	12	52		32
	20	11	38		24
	40	0	0		0
Cleaning No. 4	6	76	78		77
	10	14	26		20
	20	2	11		6
	40	0	0		0
Cleaning No. 5	6	33	21		27
	10	7	7		7
	20	0	0		0
	40	0	0		0

	Particle Size	Test 1	Test 2	Test 3	Average
Cleaning # 6	6	19,998	1,880		1,939
	10	558	518		538
	20	50	58		54
	40	5	3		4
Cleaning # 7	6	23	28		25
	10	3	3		3
	20	1	1		1
	40	0	0		0
Cleaning # 8	6	57	32		45
	10	8	9		8
	20	0	0		0
	40	0	0		0
Cleaning # 9	6	36	21		28
	10	7	4		6
	20	2	0		1
	40	0	0		0
Cleaning # 10	6	1,754	2,214	1,671	1,880
	10	413	553	353	439
	20	37	42	28	36
	40	0	2	2	2
Background	6	20	20		20
	10	6	4		5
	20	0	1		1
	40	0	0		0
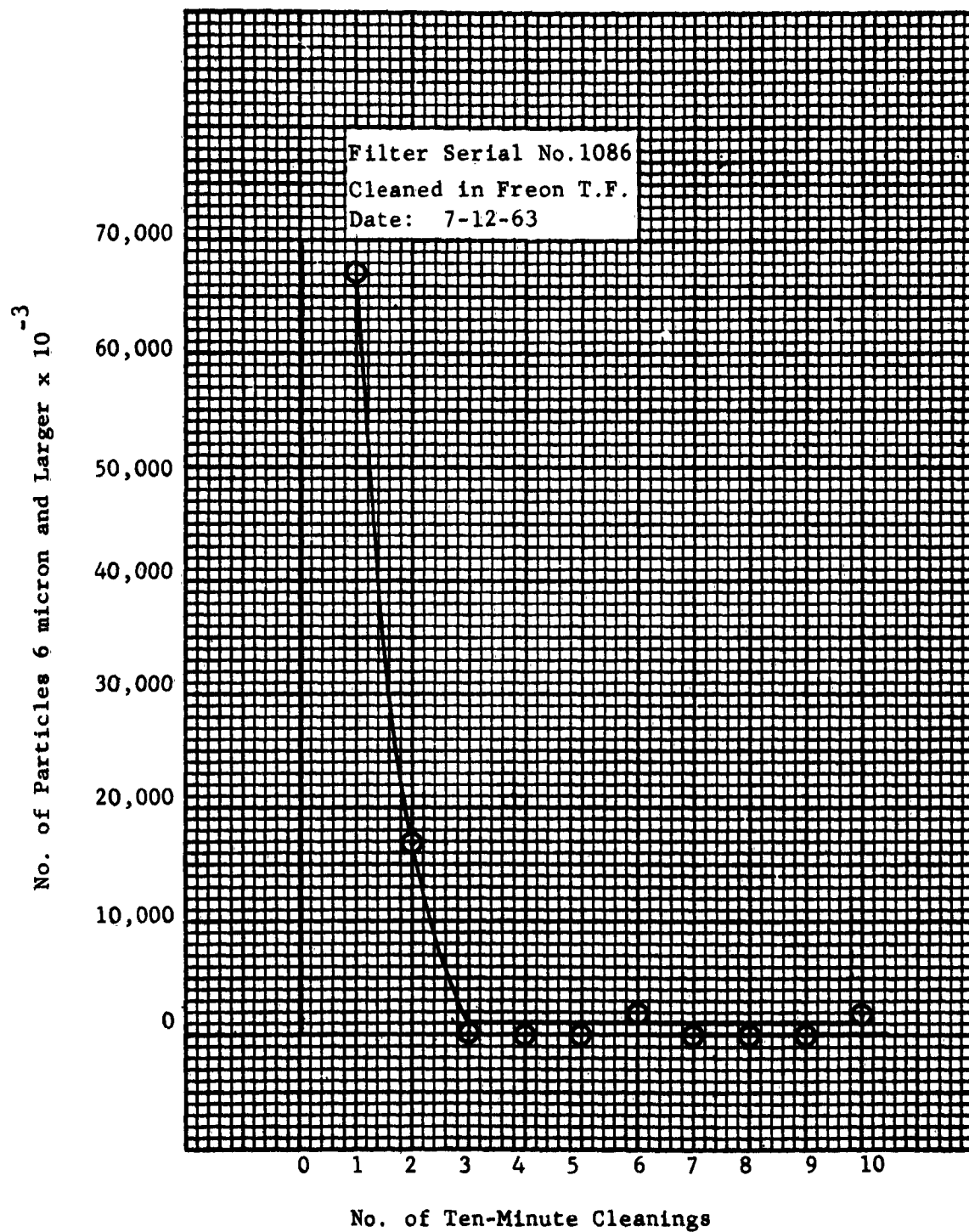
Figure 8-11 Contaminant Removal Test Results

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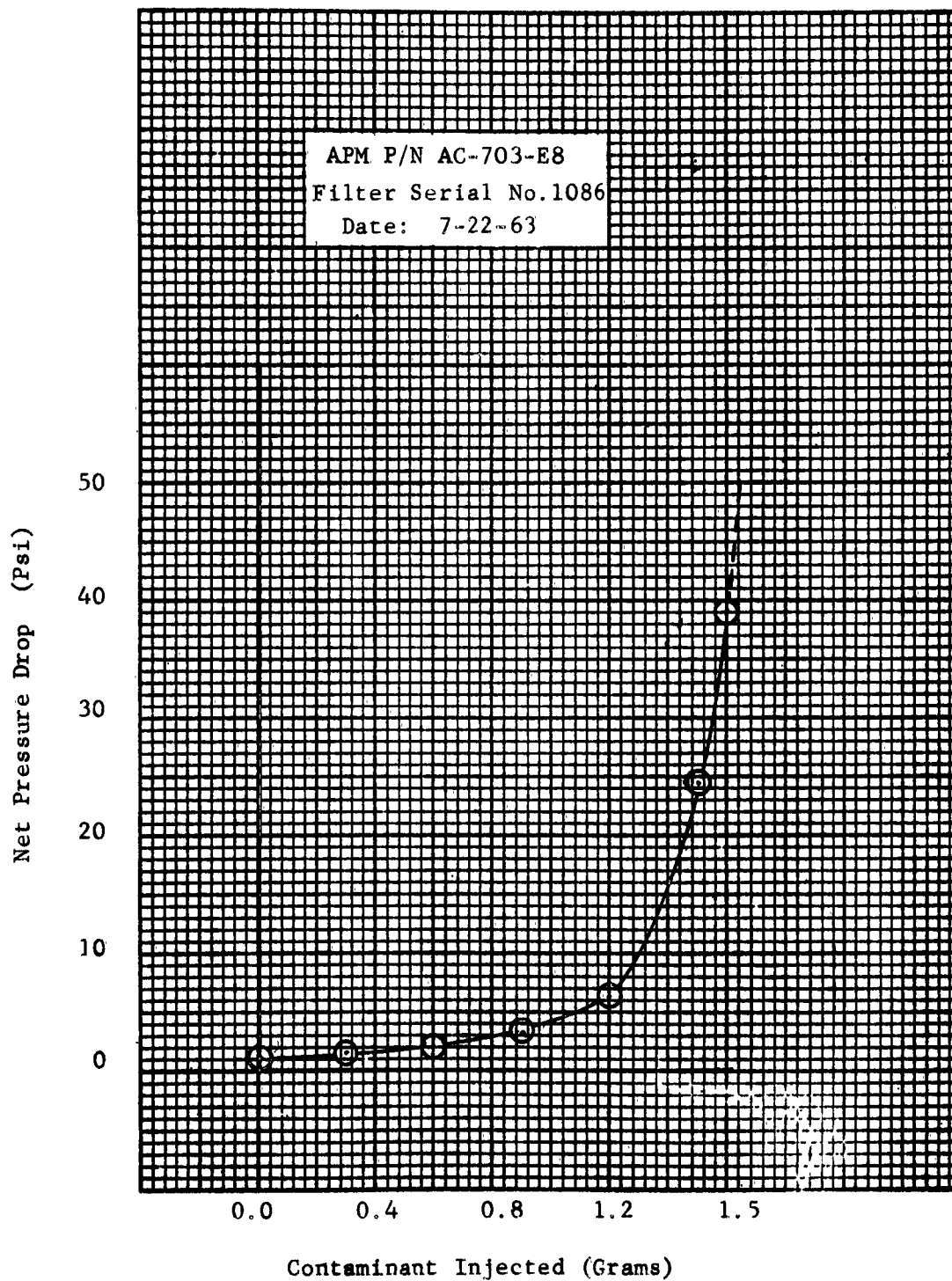
Figure 8-12 Contaminant Capacity Curve

TABLE 8-13

Filter No. 2238

Cleaned in Trichloroethylene

	Particle Size	Test 1	Test 2	Test 3	Average
Cleaning # 1	6	52,946	52,062		52,504
	10	10,812	11,208		11,010
	20	99	121		110
	40	3	4		3
Cleaning # 2	6	18,989	19,916		19,452
	10	1,858	2,289		2,073
	20	19	31		25
	40	0	0		0
Cleaning # 3	6	7,599	7,570		7,584
	10	958	986		972
	20	11	7		9
	40	1	0		0
Cleaning # 4	6	704	589		686
	10	105	89		97
	20	3	2		2
	40	1	0		0
Cleaning # 5	6	1,573	1,303		1,438
	10	148	132		140
	20	4	0		2
	40	0	0		0

Filter 2238

	Particle Size	Test 1	Test 2	Test 3	Average
Cleaning # 6	6	7,074	7,255		7,164
	10	1,583	1,815		1,699
	20	109	145		127
	40	6	7		6
Cleaning # 7	6	1,962	2,039		2,000
	10	158	208		179
	20	1	3		2
	40	0	1		1
Cleaning # 8	6	651	557		604
	10	86	95		90
	20	3	6		4
	40	0	1		0
Cleaning # 9	6	155	112		133
	10	35	22		29
	20	0	0		0
	40	0	0		0
Cleaning # 10	6	327	327		327
	10	59	65		62
	20	9	3		6
	40	1	0		1

Filter 2238

	Particle Size	Test 1	Test 2	Test 3	Average
Background # 1	6	63	71		67
	10	7	9		8
	20	0	0		0
	40	0	0		0
Background # 4	6	61	46		54
	10	12	11		13
	20	1	1		1
	40	0	0		0
Background # 7	6	199	195		197
	10	54	48		51
	20	3	6		4
	40	0	0		0
Background # 10	6	76	99		87
	10	15	23		19
	20	1	3		2
	40	0	0		0

Figure 8-13 Contaminant Removal Test Results

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APM P/N AC-703-E8
Filter Serial No.2238
Date: 7-8-63

Net Pressure Drop (Psi)

Contaminant Injected (Grams)
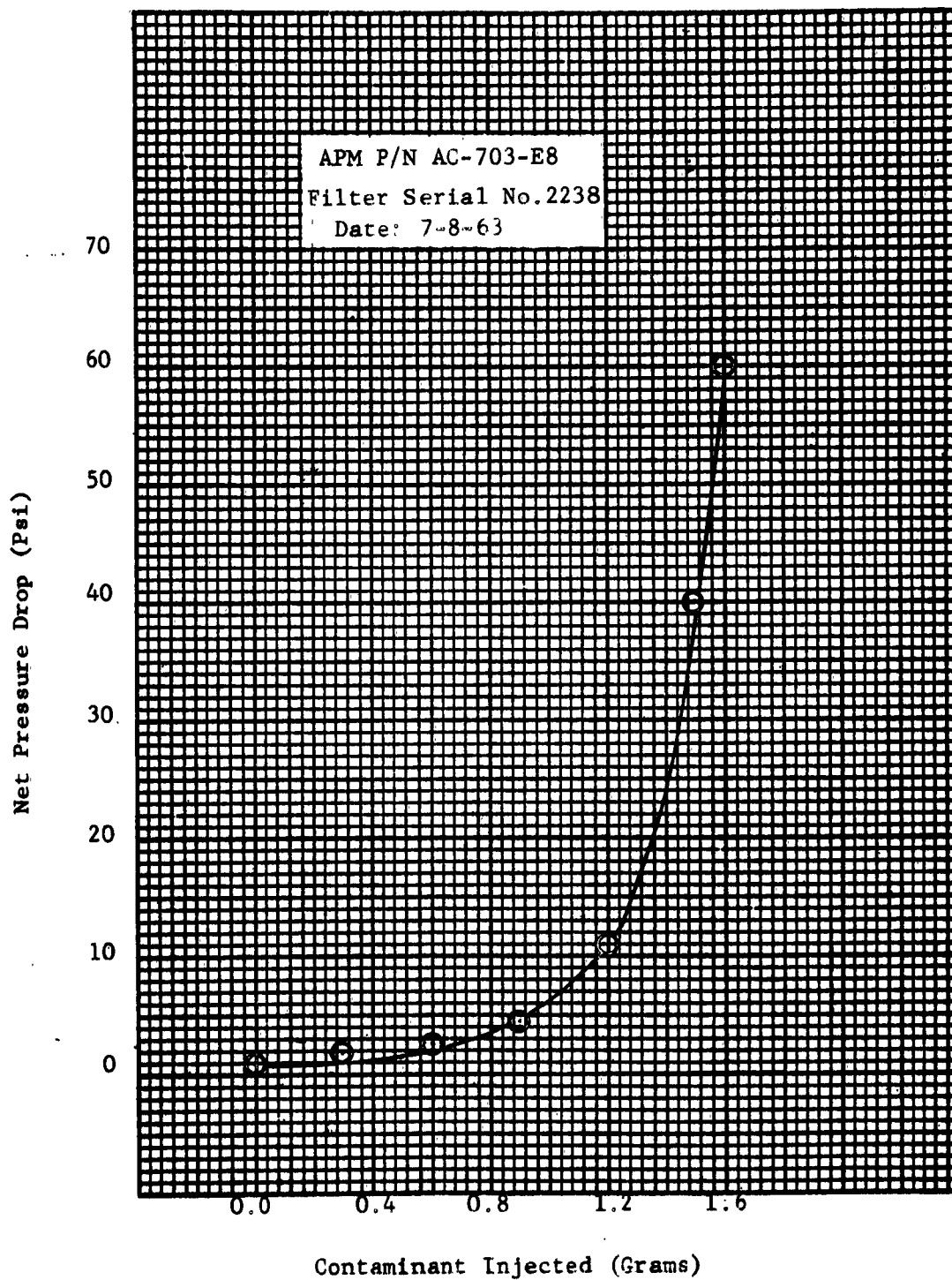
Figure 8-14 Contaminant Capacity Curve

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TABLE 8-14

Filter No. 2613

Cleaned in Trichloroethylene

	Particle Size	Test 1	Test 2	Test 3	Average
Cleaning # 1	6	41,322	32,430		36,876
	10	12,580	6,184		9,382
	20	878	314		596
	40	105	17		61
Cleaning # 2	6	18,770	20,460		19,615
	10	1,634	1,923		1,778
	20	22	25		23
	40	1	0		1
Cleaning # 3	6	6,075	6,509		6,292
	10	515	595		555
	20	12	6		9
	40	1	0		0
Cleaning # 4	6	3,534	4,525	3,898	3,986
	10	446	534	500	493
	20	3	10	16	10
	40	0	1	0	0
Cleaning # 5	6	2,116	1,805		1,960
	10	321	294		307
	20	17	24		20
	40	1	2		1

Filter No. 2613

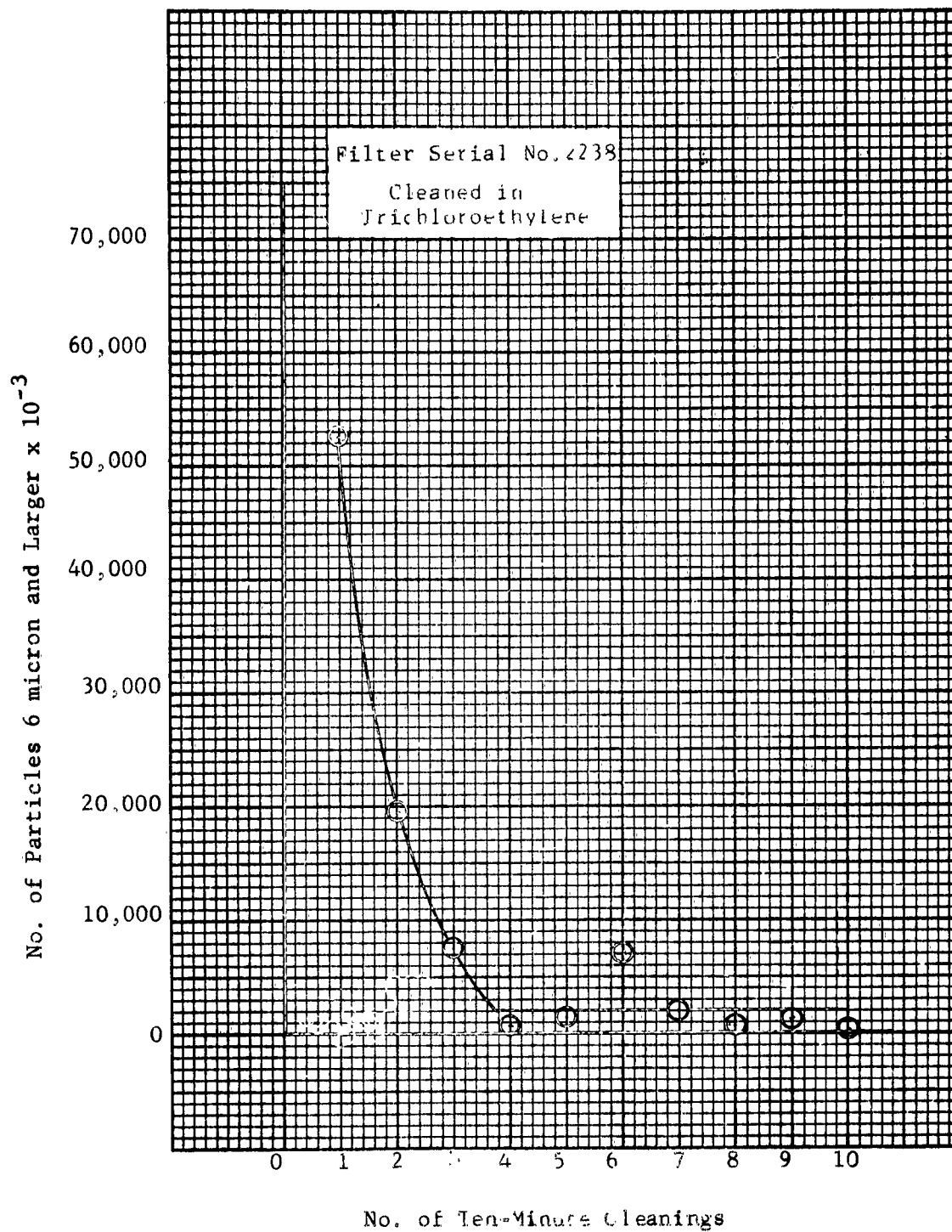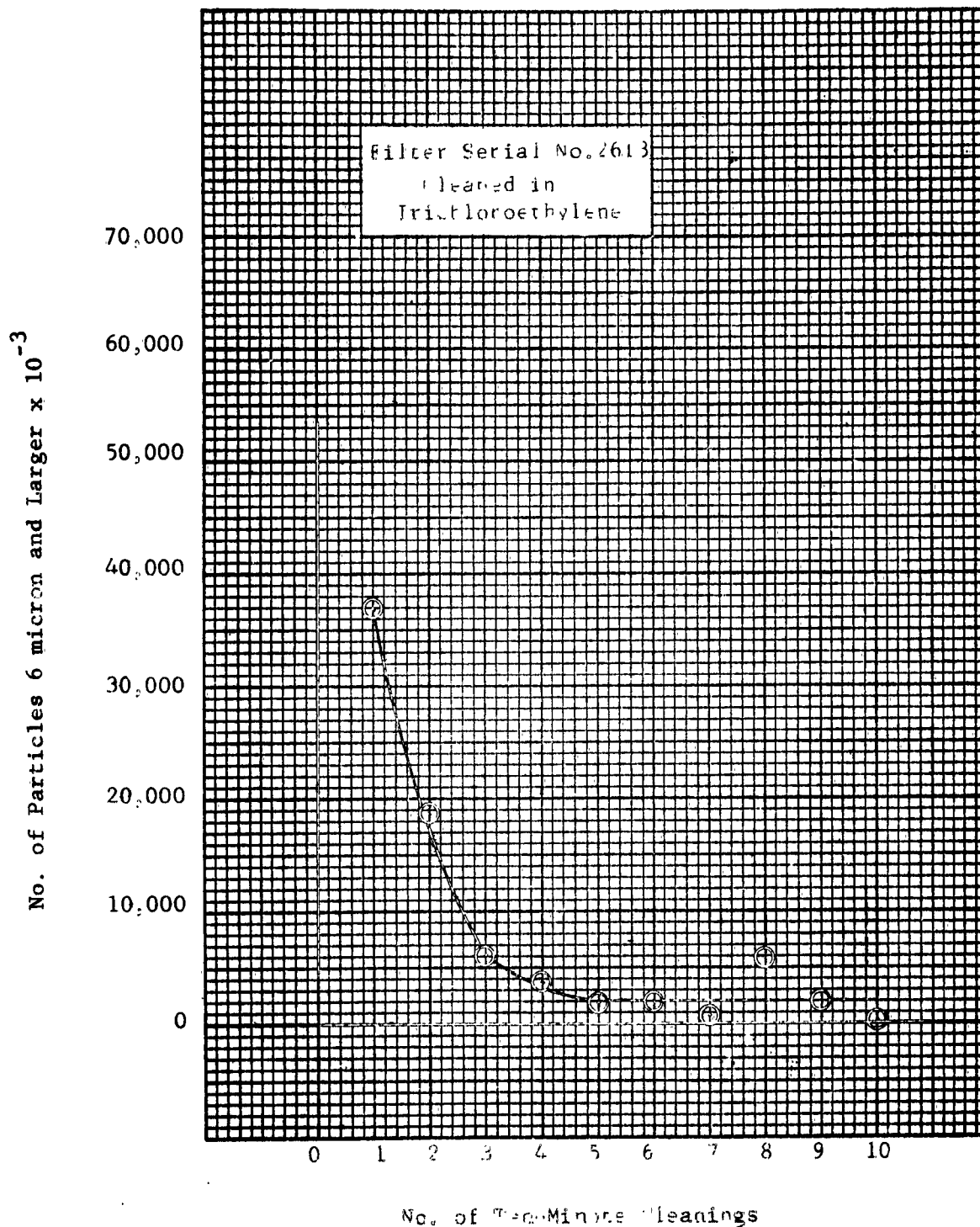|	Particle Sizes	Test 1	Test 2	Test 3	Average
Cleaning # 6	6	2,129	1,938		2,033
	10	144	131		137
	20	4	3		3
	40	0	0		0
Cleaning # 7	6	875	902		888
	10	149	165		157
	20	3	5		4
	40	0	0		0
Cleaning # 8	6	6,004	5,222	6,533	5,920
	10	1,014	864	1,208	1,029
	20	19	22	27	23
	40	1	1	1	1
Cleaning # 9	6	2,296	1,752	1,930	1,993
	10	462	413	419	431
	20	28	23	21	24
	40	2	0	0	1
Cleaning # 10	6	304	324		314
	10	88	96		92
	20	5	8		6
	40	1	2		1
Background	6	129	111		120
	10	30	33		31
	20	5	5		5
	40	2	0		1

Figure 8-15 Contaminant Removal Test Results

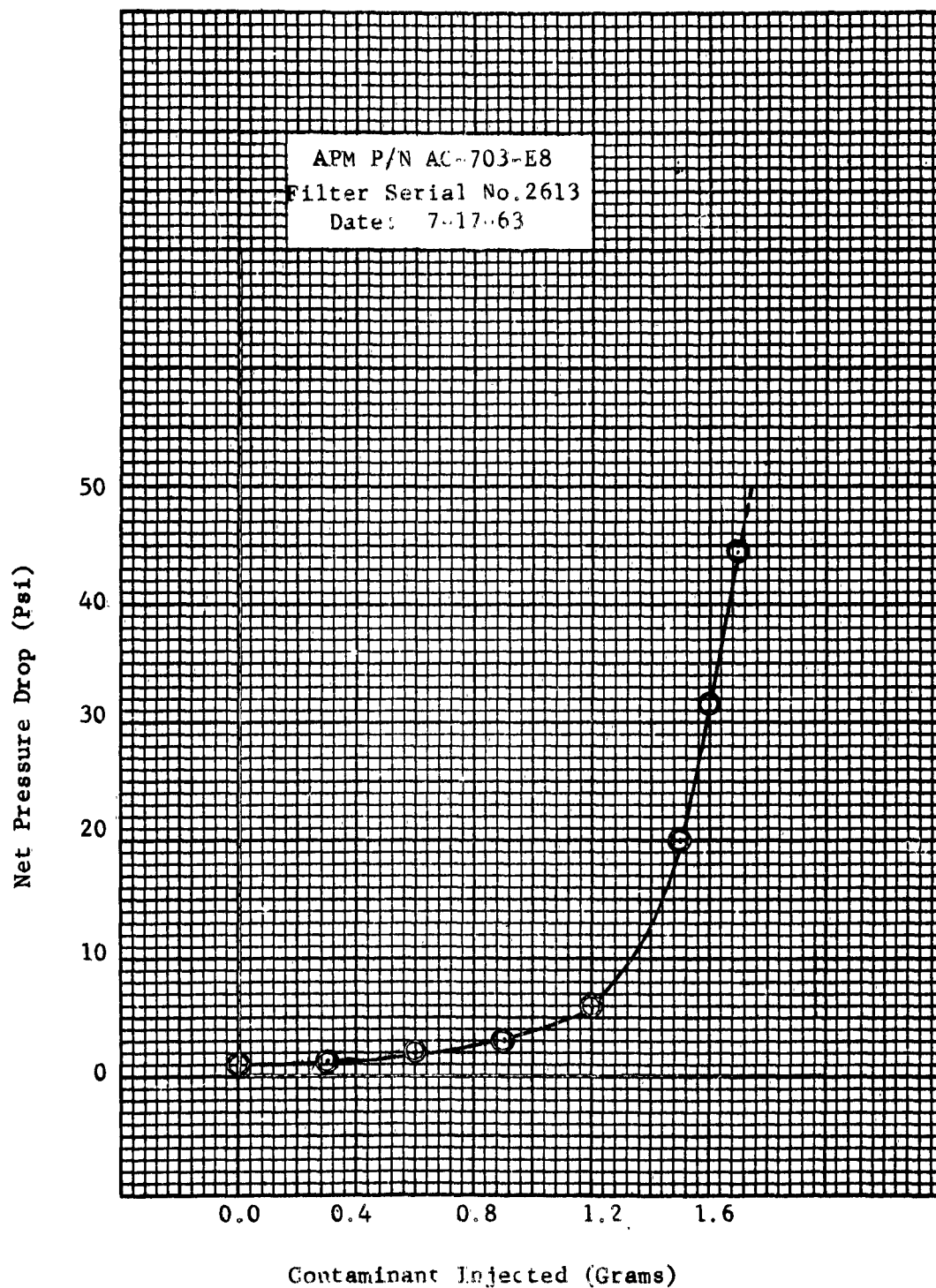Figure 8-16 Contaminant Capacity Curve

TABLE 8-15

Filter No. 4478

Cleaned in Freon T. F.

	Particle Size	Test 1	Test 2	Test 3	Average
Cleaning #1	6	60,499	76,003	85,724	**74,075**
	10	19,464	25,263	80,805	**25,177**
	20	1,442	1,514	1,690	**1,549**
	40	86	92	137	**105**
Cleaning # 2	6	52,224	66,696	66,626	**61,849**
	10	8,241	5,217	10,006	**7,821**
	20	1,397	752	1,481	**1,210**
	40	67	51	98	**72**
Cleaning # 3	6	30,954	39,966	41,219	**37,380**
	10	7,332	8,777	10,968	**9,026**
	20	556	585	915	**685**
	40	30	36	113	**59**
Cleaning # 4	6	2,148	3,485	1,544	**2,392**
	10	182	245	145	**191**
	20	4	7	9	**8**
	40	0	1	0	**0**
Cleaning # 5	6	7,554	8,576		**8,065**
	10	1,794	1,576		**1,685**
	20	75	50		**67**
	40	3	2		**2**

Filter 4478

	Particle Size	Test 1	Test 2	Test 3	Average
Cleaning #6	6	2,290	2,907	3,778	2,991
	10	387	725	837	650
	20	15	45	41	34
	40	1	0	2	1
Cleaning #7	6				
	10		VOID		
	20				
	40				
Cleaning #8	6	5,760	6,571		6,165
	10	1,283	1,325		1,304
	20	80	79		79
	40	6	8		7
Cleaning #9	6				
	10		VOID		
	20				
	40				
Cleaning #10	6	531	461		496
	10	122	103		112
	20	10	13		12
	40	0	0		0

Filter No. 4478

	Particle Size	Test 1	Test 2	Test 3	Average
Background # 7	6	48	26		37
	10	9	9		9
	20	2	5		4
	40	0	0		0
Background # 8	6	162	136		149
	10	32	26		29
	20	2	1		2
	40	0	0		0
Background # 9	6	188	156		172
	10	66	35		51
	20	5	2		4
	40	1	1		1

No. of Ten-Minute Cleanings
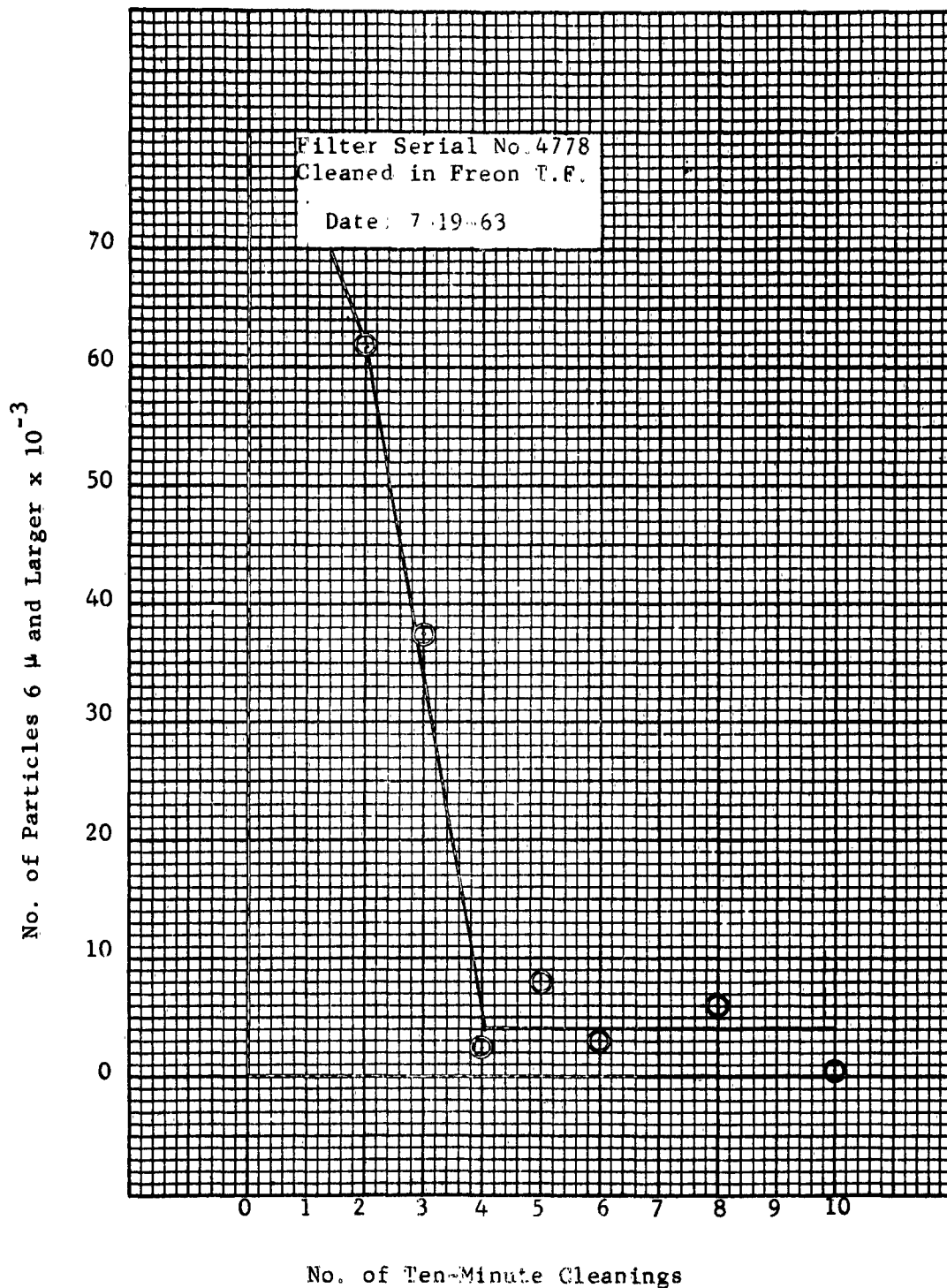
Figure 3-17 Contaminant Removal Test Results

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APM P/N AC-703-E8
Filter Serial No.4778
Date: 7-18-63

Net Pressure Drop (Psi)

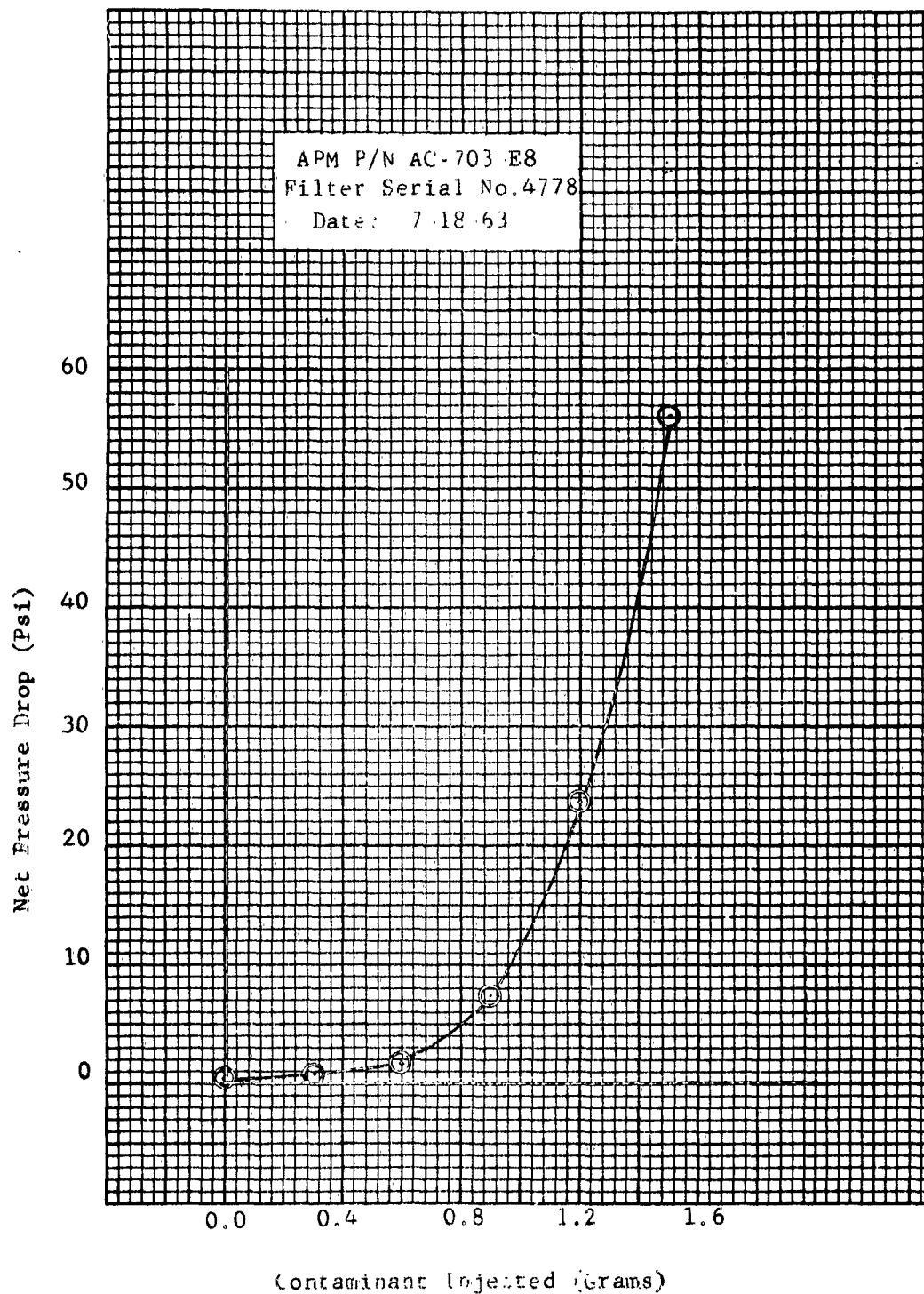Contaminant Injected (Grams)

Figure 8-18 Contaminant Capacity Curve

TABLE 8-16

Filter No. 4438

Cleaned in Trichloroethylene

	Particle Size	Test 1	Test 2	Test 3	Average
Cleaning # 1	6	69,135	66,474		67,804
	10	14,540	15,210		14,875
	20	782	856		819
	40	48	60		54
Cleaning # 2	6	42,440	40,865		41,652
	10	8,521	9,323		8,922
	20	408	458		433
	40	15	26		20
Cleaning # 3	6	1,763	1,814		1,788
	10	463	476		469
	20	41	54		47
	40	0	0		0
Cleaning # 4	6	2,864	2,406		2,635
	10	734	603		668
	20	74	60		67
	40	1	5		3
Cleaning # 5	6	3,313	3,543		3,428
	10	528	569		548
	20	30	26		28
	40	2	1		2

Filter No₀, -4438

	Particle Size	Test 1	Test 2	Test 3	Average
Cleaning # 6	6	1,622	1,442		1,532
	10	306	294		300
	20	300	17		23
	40	2	0		.1
Cleaning # 7	6	1,234	1,278		1,256
	10	153	142		148
	20	8	8		8
	40	0	0		0
Cleaning # 8	6	4,075	4,207		4,141
	10	1,016	905		960
	20	51	61		56
	40	5	3		4
Cleaning # 9	6	1,718	2,161		1,939
	10	360	424		392
	20	40	37		38
	40	1	3		2
Cleaning # 10	6	2,973	3,669		3,321
	10	386	493		439
	20	25	32		28
	40	2	1		1

No. of Particles 6 micron and Larger $\times 10^{-3}$

No. of Ten-Minute Cleanings

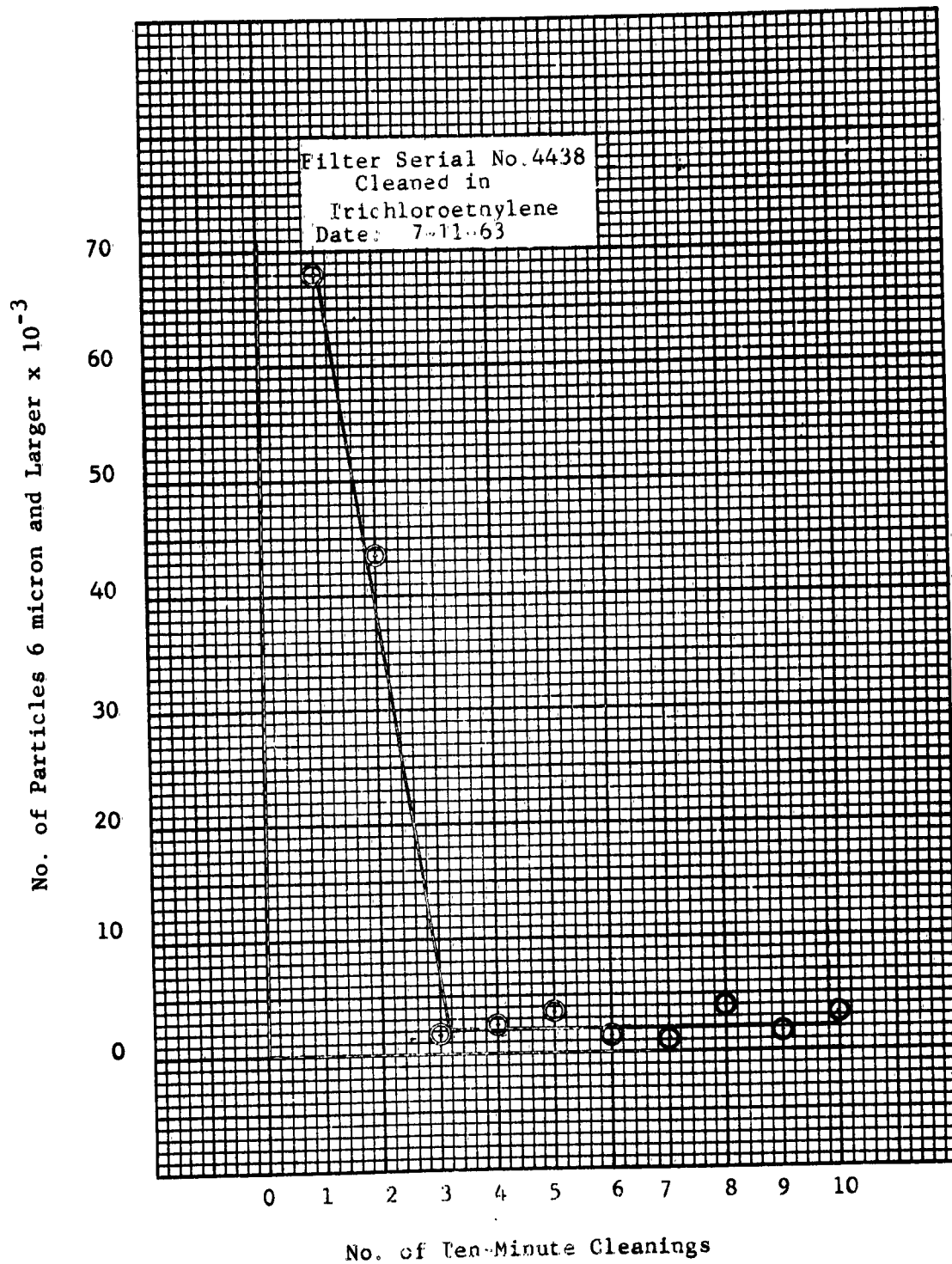Filter Serial No. 4438
Cleaned in
Trichloroetnylene
Date: 7-11-63

Figure 8-19   Contaminant Removal Test Results
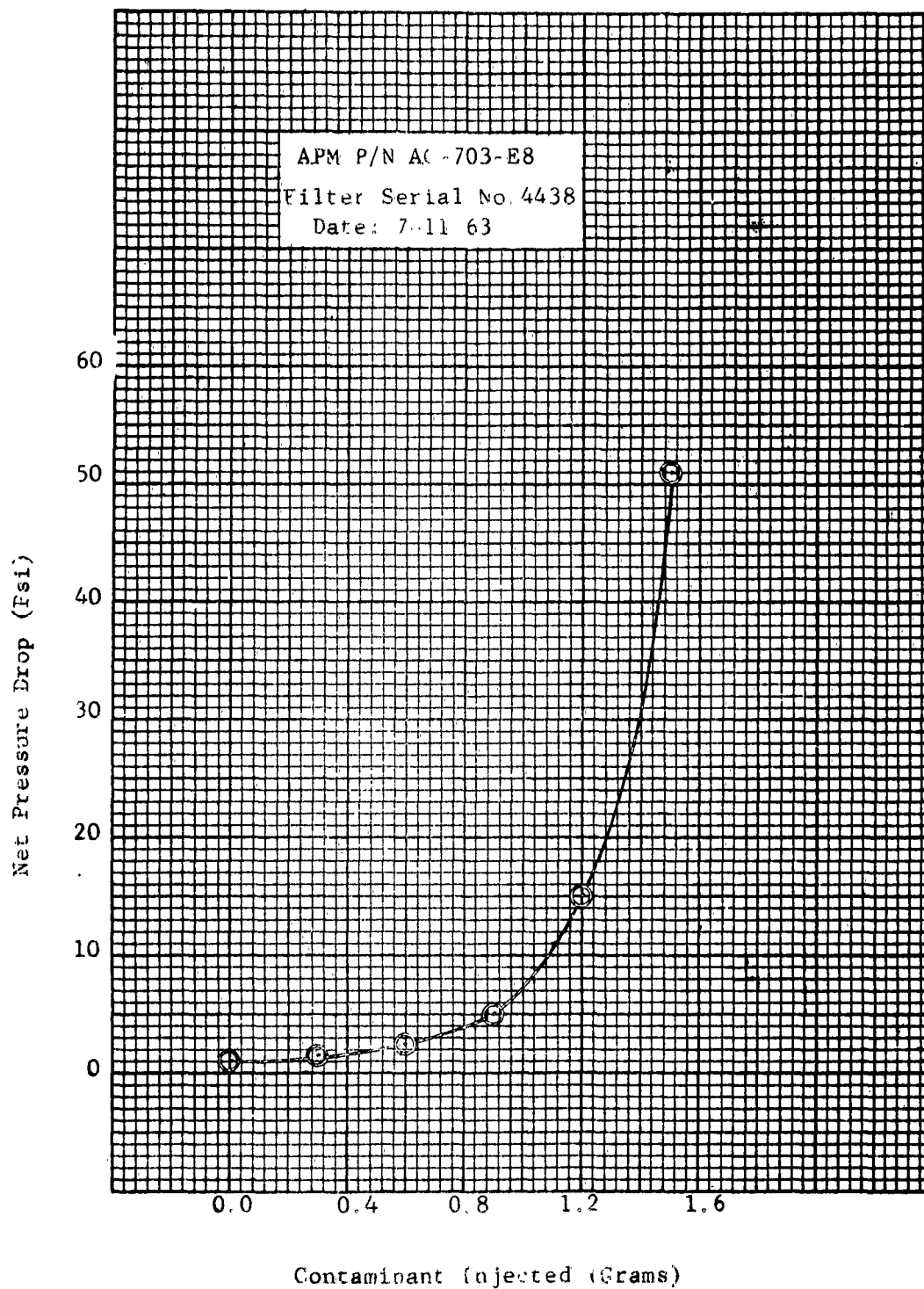
Figure 8-20 Contaminant Capacity Curve

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